Spectra Technology

WINDVAN LASER STUDY

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WINDVAN LASER STUDY

Final Report

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George C. Marshall Space Flight Center
Marshall Flight Center, Alabama 35812

By

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INTRODUCTION

1.1 BACKGROUND

There is a growing concensus that global mapping of winds could have an enormous impact on both weather prediction and fundamental atmospheric science. Doppler lidar used from an earth orbiting platform appears to be an ideal approach for such measurements. The remote Doppler approach simultaneously provides excellent spatial and temporal coverage, combined with good spatial and velocity resolution.

The technical capability of the Doppler lidar approach has been demonstrated over the last five to ten years. Although Doppler measurements can in principle be made at any wavelength, the 9-11 μm band has been used for all existing Doppler wind velocity measurements. This wavelength region is attractive for its good atmospheric transmission and reasonably large aerosol backscatter cross-section. This wavelength selection has also been strongly driven by the existence of the CO_2 laser, which is one of the oldest and best developed of all pulsed laser technologies.

Two developments in wind measurement account for much of our confidence in the Doppler lidar approach. A system developed by MSFC/Raytheon has produced a wide range of data from both airborne and ground based platforms. More recently, a mobile ground based system using pulsed TEA CO_2 technology has been developed at NOAA/WPL, originally using lasers developed by UTRC.

The MSFC system has shown the value of lidar deployment on highly mobile platforms for providing wide geographic coverage in a short time. However, because of the relatively low laser power available in the existing MSFC lidar, measurements can be made only at short ranges from the

aircraft. The corresponding NOAA lidar has demonstrated the capability of making high quality longrange measurements. The NOAA system routinely measures to and beyond the tropopause when operated from its ground based platform in midlatitude locations. SCALE can be viewed as a marriage of the mobility and long range capability o these two systems.

At the present time, the NOAA system is being upgraded to incorporate a new high power laser transmitter developed by Spectra Technology, Inc. The NOAA/STI laser system will increase the pulse energy by a factor of twenty, the pulse repetition rate by a factor of five, and the the velocity resolution by a factor of two, when compared with the existing capability. These transmitter capabilities are summarized in Table 1-1.

1.2 STUDY OBJECTIVES

This study has the goal of defining a CO_2 laser transmitter approach suited to SCALE requirements. Since the NOAA/STI WINDVAN transmitter meets the basic SCALE performance requirements (but in a ground based environment), our study has specifically addressed the adaptation of the existing WINDVAN design to the shuttle environment.

The study is intended to produce several results. First, we compare the needed performance (energy, coherence, repetition rate, size, weight, and reliability) of a conceptual SCALE transmitter with existing carbon dioxide laser technology. This comparison results in a statement of the anticipated performance of a SCALE transmitter, along with the time and cost for development of such a transmitter. A preliminary definition of STS interfaces results from this conceptual design. Finally, a qualitative assessment of the technical risk accompanying this development is given.

1.3 METHODOLOGY

The existing WINDVAN design has been evaluated subsystem by subsystem for compatibility both with SCALE performance requirements, and for

Table 1-1

NOAA WINDVAN SPECIFICATIONS

High Energy and Average Power	100 W (2 J @ 50 Hz)
Low Frequency Uncertainty	Chirp < 200 kHz Offset < 500 kHz
Wide Line Tunability	> 10 lines in 9 and 10 μm bands
Low Afterpulse	< 10^{-5} Watts after 8 μsec
Pulse Length Agility	> → 5 μsec
High Reliability	> 2 x 10^8 shots between maintenance cycles
Compactness	Fit within existing 1 Watt system space constraints
Fully Automated	Line changing, servo-lock, startup/shutdown, etc.
Wide Operating Range	0-14,000 ft., 18 to 30°C

compatibility with the shuttle bay environment. The study presumed that WINDVAN designs would be used with as little modification as possible to meet SCALE requirements.

In evaluating shuttle compatibility, we have assumed that it will be possible to use a Spacelab pallet and the accompanying electrical, thermal, and data support systems. This assumption has proven invaluable by defining well documented interfaces, and no incompatibility with the Spacelab infrastructure has been observed.

MSFC has provided extensive support to this study both by providing detailed discussion (and iteration) of SCALE transmitter performance requirements, and by transferring considerable detailed information concerning the STS bay environment. This cooperation is gratefully acknowledged.

1.4 SUMMARY OF CONCLUSIONS

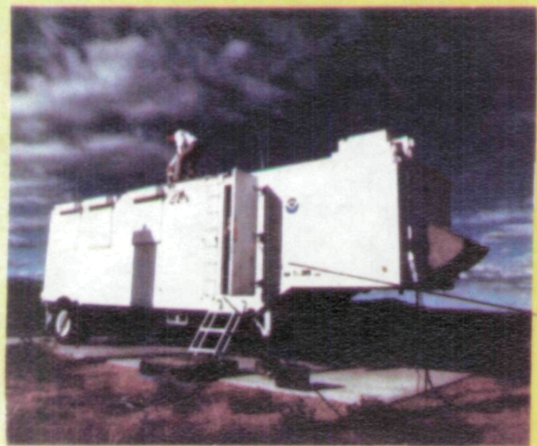
The adaptation of the existing WINDVAN design to a one week shuttle flight appears to be entirely feasible. No new technology development is required for STS operation. The size, weight, and reliability, and efficiency of the existing WINDVAN system are largely compatible with SCALE requirements.

It should come as no surprise that an appreciable engineering development effort will be required to bring WINDVAN into compliance with STS bay operational requirements. Some repackaging is needed for compatibility with the vacuum and thermal environments. The largest changes will be required to ensure survival through launch and landing, mechanical, vibration and acoustic loads. Remote hands-off operability requires enhancement of command, control and optical alignment subsystems. Existing WINDVAN thermal management approaches which depend on convection must be upgraded for 0g operation.

In summary, we believe that the existing WINDVAN design can be extended to STS operation through a predictable and manageable set of engineering revisions. The risk entailed in this program appears to be manageable, since no new technological development is required.

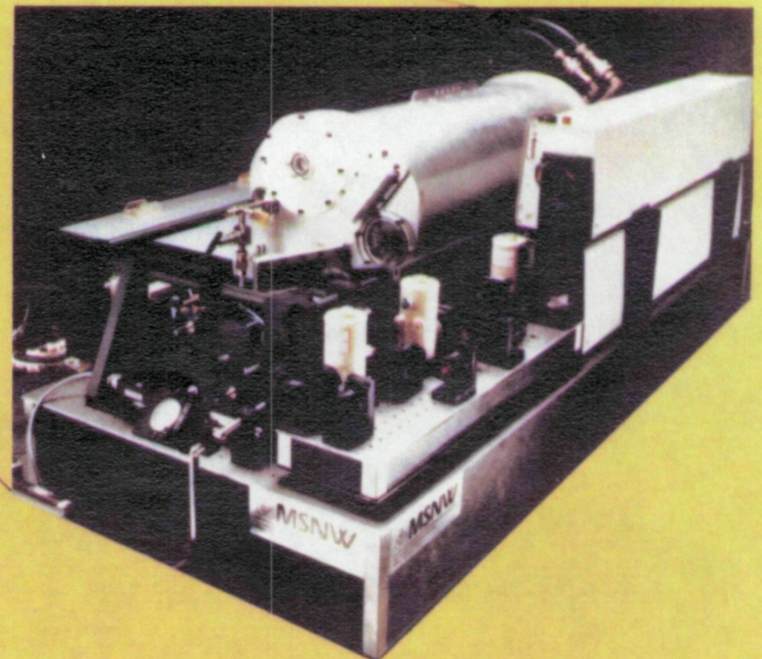
Figure 1-1 is a photograph of the WINDVAN transmitter. The similarities between it and the artist's concept of the SCALE transmitter are shown in Figure 1-2.

NOAA "WINDVAN" CO_2 LIDAR UNIT



MOBILE TRAILER

LASER TRANSMITTER



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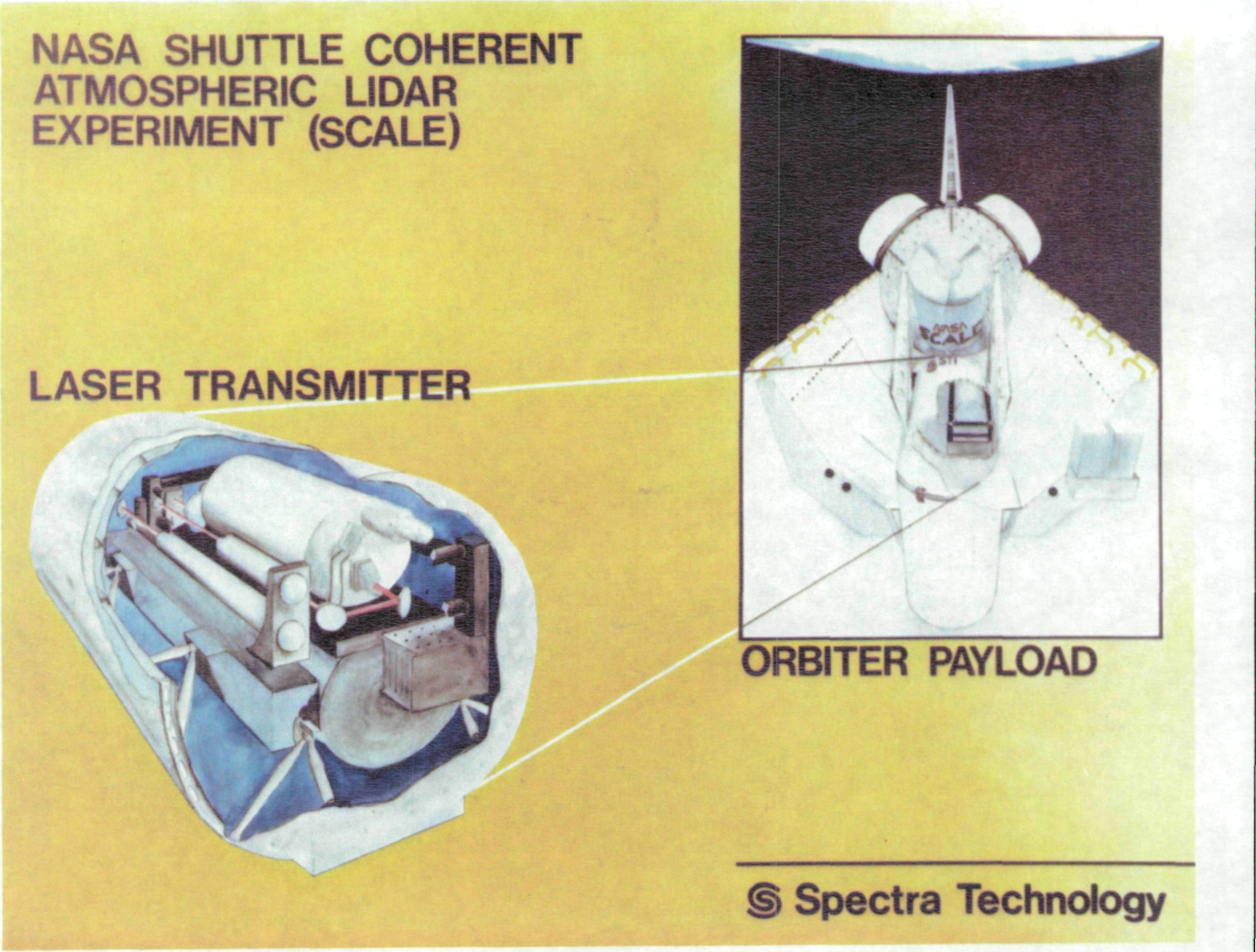
NASA SHUTTLE COHERENT
ATMOSPHERIC LIDAR
EXPERIMENT (SCALE)
LASER TRANSMITTER
ORBITER PAYLOAD
Spectra Technology

Section 2

SCALE TRANSMITTER CONCEPT

2.1 SYSTEM OVERVIEW

The specifications for the SCALE transmitter listed in Table 2-1. The lidar Laser System contains both pulsed transmitter and cw local oscillator lasers. A third laser, another cw laser referred to as the injection oscillator, serves as a frequency reference for the entire systems. Figure 2-1 is a conceptual layout of the entire system. Schematically the SCALE system is identical to the WINDVAN.

The injection oscillator and local oscillator for the WINDVAN are both commercial, low pressure longitudinal discharge cw lasers made by Ultra-Lasertech, of Canada. All three lasers have diffraction gratings in their cavities to force operation on a single rotational line of CO_2. Hardened versions of these lasers are available which meet military specifications from vendors such as Hughes Aircraft.

The injection oscillator (IO) is locked to CO_2 line center by searching for maximum intensity vs cavity length. The cavity length is modulated ("dithered") with an amplitude equivalent to 0.5-1 MHz. The laser output is sampled by a HgCdTe detector. The dc length is adjusted by a standard linear hill climbing servo approach which finds the point of zero derivative. This fixed frequency (except for the dither) signal effectively serves as the reference for the entire system.

The local oscillator is offset locked with respect to the injection oscillator, using another HgCdTe detector and a frequency counting based loop. The effect of the IO dither is eliminated from this loop by always counting the beat frequency for entire dither period, so that the frequency variation averages to zero over any given measurement. The beam from the

Table 2-1

SCALE TRANSMITTER SUBSYSTEM PRELIMINARY REQUIREMENTS

LASER

- 2 J Pulse Energy
- 50 Hz Repetition Rate *
- 4 μs Pulse Duration
- 5% Wall Plug Efficiency
- Isotopic Gas (9.11 μm)
- 10^7 Shot Lifetime
- Nonrecycling Operation

* Reducing Rep Rate to 25 Hz May Best Fit Overall Mission Constraints

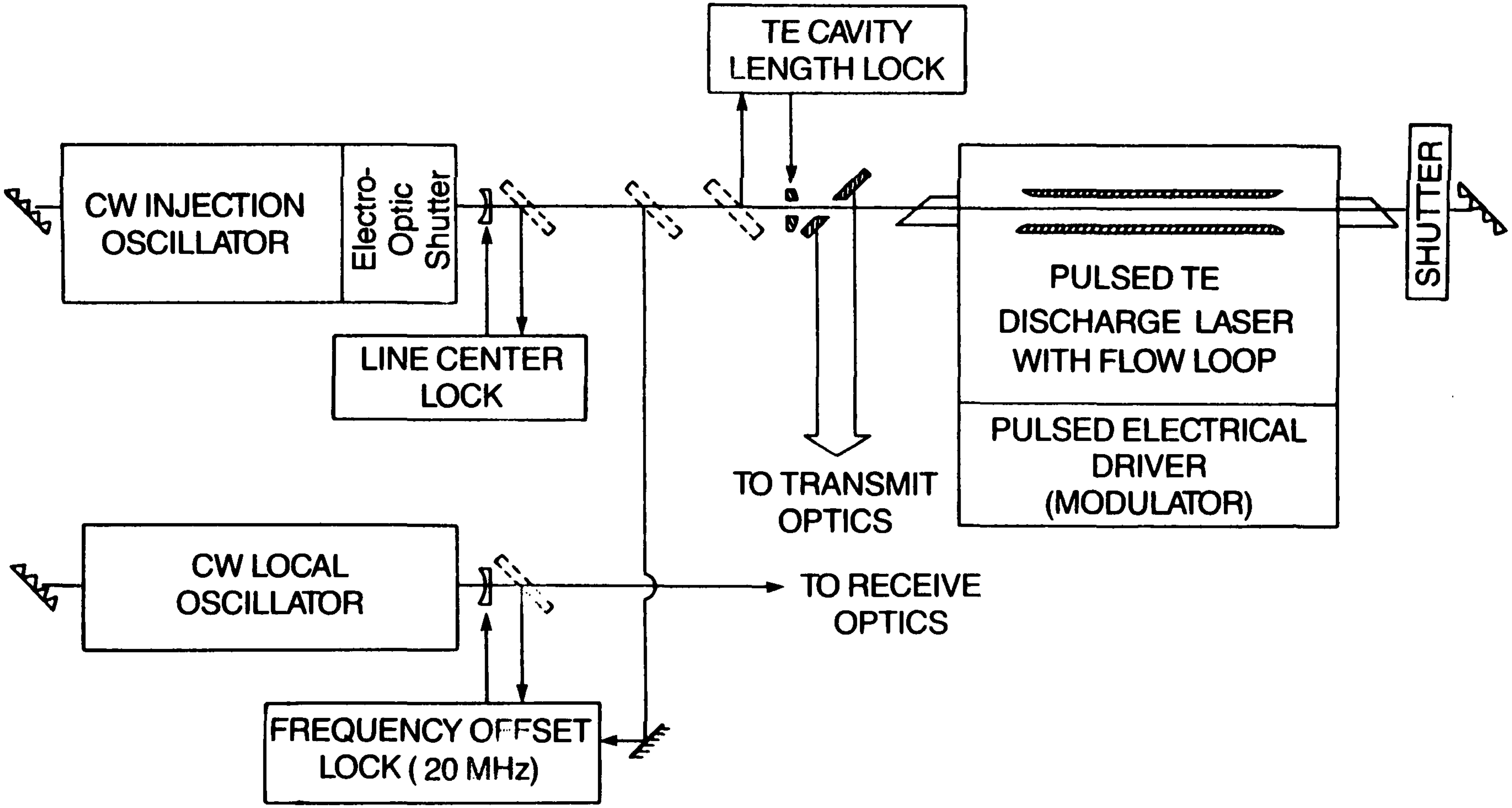

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Figure 2-1. Conceptual Design for High Average Power Lidar Upgrade

local oscillator is delivered to the edge of the table for use in the interferometer, and has no other role in the laser system.

The heart of the system is of course the pulse TE laser. This device is a large aperture, low pressure self-sustained discharge device, which is described in Section 3.1. The TE laser uses an unstable resonator, which is described in Section 3.5. The TE laser resonator is injected with light from the IO, forcing single longitudinal mode operation. For injection to be successful, the injection frequency must agree with a longitudinal mode frequency of the transmitter resonator. This resonant condition is enforced by a servo loop on the power oscillator (PO) cavity length. More detail on this process is given in Section 3.5

The system is operated by an integrated computer control system, which is interfaced to all relevant external sensors and actuators,and to the servo loop electronics. Our approach of integrating all functions in a single unit has led to a number of advantages. Using this approach it is straightforward to allow computer control of servo loop parameters, which, in turn, allows easy implementation of automatic locking of the servo loops. It also allows all time-dependent signals to be derived from a single clock, so that synchronism of various events is easily ensured.

2.2 FUNCTIONAL FLOW

As a prerequisite to an evaluation of any system as complex as the SCALE transmitter, division into subunits according to function must be performed. Figure 2-2 shows the five major transmitter subsystems and how they interact with one another. Two central boxes, the mechanical and electrical subsystems, contain the components of the TEA laser. The other boxes include the gas makeup system, the optical/structural system, the thermal system and the data handling and control system. The subsystems themselves as well as the components within the subsystems may then be isolated and evaluated in terms of suitability for meeting the design goals.

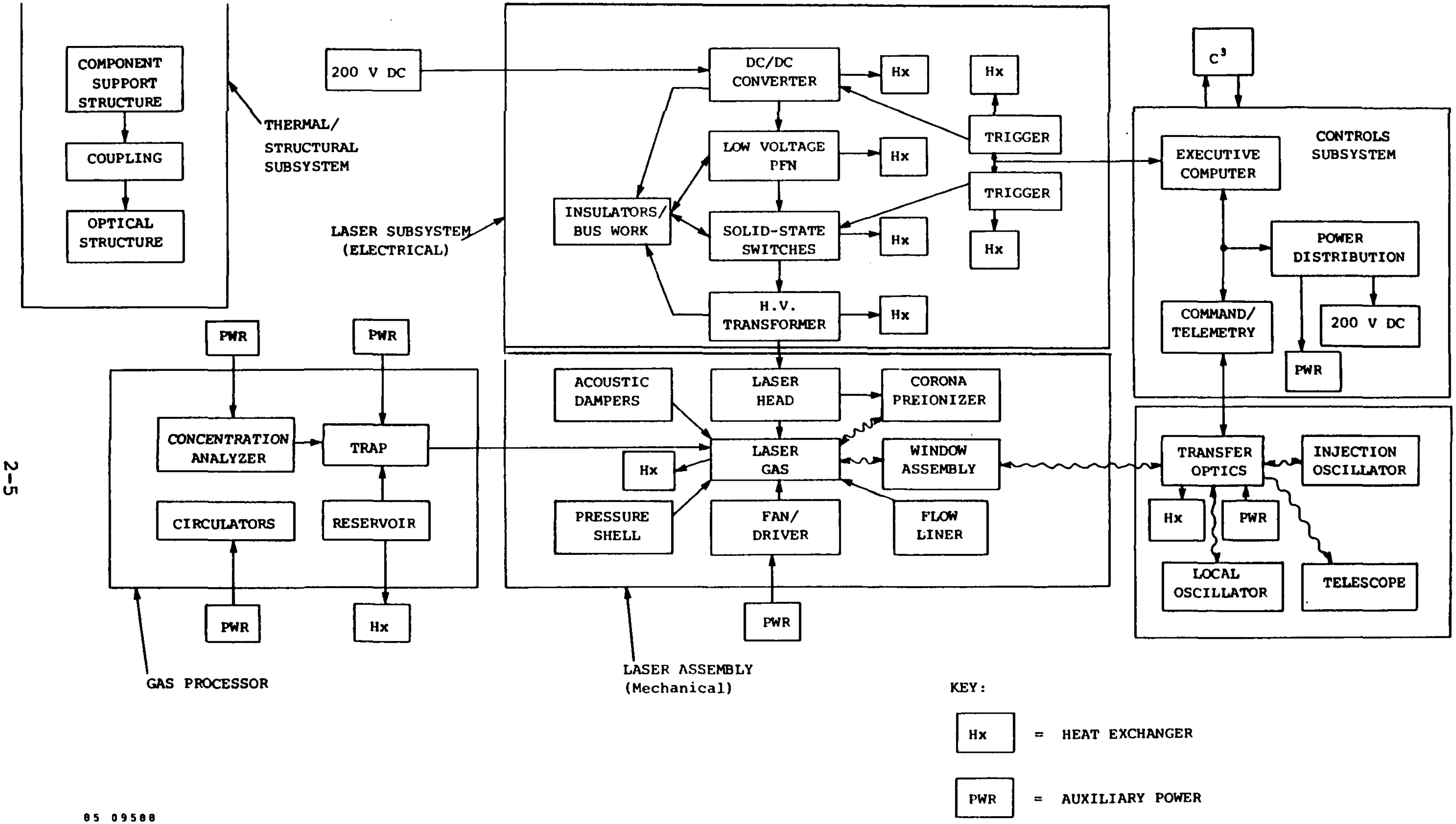


Figure 2-2. Functional Flow Diagram for NASA CO_2

2.3 RISK ASSESSMENT

To evaluate risk, an assessment formalism is employed which assigns numerical factors to the components in three categories: the level of development to which the item has been carried, the amount of supporting analysis which is available and the degree to which the component is critical to the success of the mission. The risk score is the product of the three values. Table 2-2 illustrates this rating system. Scores may be used to establish the readiness of individual components. They may also be summed to determine the overall readiness of the subsystem. This approach is used for each subsystem to evaluate the potential of the transmitter system to perform the SCALE mission. The results are tabulated for each of the subsystems and are used to indicate where resources might be spent on further development in order to insure success.

2.4 INTERFACE

The primary output of this study is a determination of transmitter feasibility for the SCALE mission. This is in turn dependent on the ability of the transmitter to utilize onboard services of the shuttle. To simplify this determination the extensive documentation provided for the ESA Spacelab pallet was used to establish the interface requirements and to configure the payload in the cargo bay. Results for each laser subsystem are tabulated in terms of the demands placed on the shuttle resources including power, weight, volume, heat rejection, and data.

Table 2-2

NUMERICAL FACTORS FOR RISK ASSESSMENT

CATEGORY	NATURE OF DEVELOPMENT		CATEGORY	SUPPORTING ANALYSIS/DATA		CATEGORY	FUNCTIONAL CRITICALITY		RISK PRODUCT
	SUBSET	VALUE		SUBSET	VALUE		SUBSET	VALUE	
1	RESEARCH	16	1	NONE	4	1	HIGH	3	
2	FEASIBILITY DEMONSTATION	8	2	MINIMAL	3	2	MODERATE	2	
3	ENG. DEVELOP. FOR SYS. TEST	4	3	PARTIAL	2	3	LOW	1	
4	ENG. FOR SPACE DESIGN	2	4	FULL	1				
5	SPACE QUALIFICATION	1							

Section 3

LASER TRANSMITTER SUBSYSTEMS

Table 3.1-1 lists the subsystems of the SCALE transmitter along with the major components. In the sections which follow, the functins of each of the subsystems is discussed and an assessment of the radiness of each is presented.

3.1 LASER MECHANICAL

The pulsed transmitter is a discharge pumped transverse discharge device. The dimensions of the discharge are 4X4X60 cm. These dimensions were chosen to minimize chirp, and the geometry of the device is quite different from a 2 J laser not designed for lidar application. The device is designed to operate at a total pressure of approximately 0.5 atm.

The discharge is preionized by a "corona" type UV source. Preionization is required to allow an initial small level of conductivity to support smooth initiation of the main discharge. Attempts to operate the discharge without preionization result in nothing but a single concentrated arc somewhere between the electrodes. This preionization source is simple, compact, and so far as proven reasonably reliable. The corona source is a large area insulate conductor located just behind one of the electrodes, which is made of screen to allow passage of the UV radiation. UV is generated by the capacitive charging of the insulator surface across a small gas gap.

The corona bar is pulsed using a passive circuit approach. Essentially, the corona is driven during the leading edge of the main discharge pulse while the instantaneous voltage betweeen the screen electrode and te corona bar is changing quickly. Separate active corona bar drivers were tried during the development of the laser, and did not give results superior to the simple passive approach.

Table 3.1-1

SCALE LASER TRANSMITTER SUBSYSTEMS AND COMPONENTS

SUBSYSTEM	COMPONENT
Laser (Mechanical)	Transverse Fan
	Bearing
	Fan Motor
	Magnetic Coupling
	Drive Coupling
	Flow Liner
	Ground Electrode
	HV Electrode
	Pressure Shell
Power Modulator	DC/DC Converter
	Low Voltage PFN
	Solid State Switch
	High Voltage Transformer
	Trigger Assembly
Thermal	Freon Pump Package
	Experiment Heat Exchanger
	Laser Heat Exchanger
	Modulator Pump
	Modulator Flow Ducting
Gas Regeneration	Blower
	Regenerative HX
	Catalyst Container
	Catalyst Charge
	Catalyst Heater
	Filter
Optical/Structural	Optical Table
	Cavity Space Frame
	Infrared Detectors
	Oscillators
	Servo Sub-Bench
	TE Laser Resonator
	Acoustic Shell
Data and Control	Telemetry Interface
	Supervisory Computer
	Control Electronics and Sensors

The discharge is pulsed by a circuit (the "modulator", see Section 3.2) which applies about 30 kV to the electrodes for a period of 500 nsec. The peak discharge current is in excess of 3000 amps. Total energy deposited in the gas by the pulser is about 40 J.

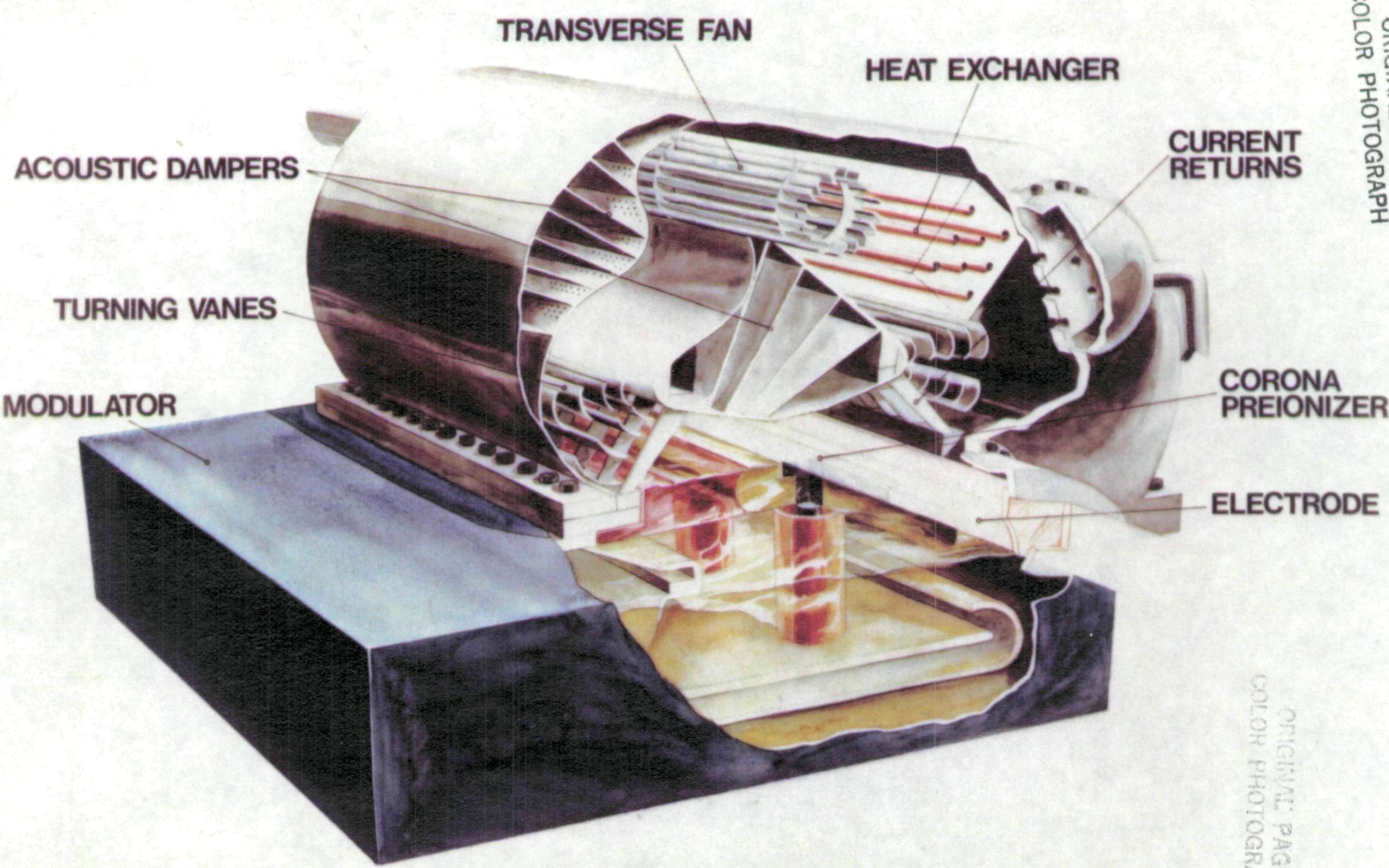
Gas is flowed through the discharge volume at a rate sufficient to support 50 Hz operation. This requires a minimum of approximately 2 gas exchanges per 20 msec. The cylindrical shell of the TE containment vessel essentially forms the outer wall of the flow duct as well. The inner wall consists of the center section, which does double duty as the ground electrode. A series of vanes connects the ground electrode to the main flange to provide a low impedance electrical return path while simultaneously causing minimum perturbation of the gas flow.

The center section of the flow loop is divided into compartments which form acoustic dampers. The entrance port for the dampers is a screened slot which runs the full length of the discharge region, and is located just downstream from the discharge. These dampers function to rapidly dissipate high frequency pressure fluctuations that result from the impulsive heating of the gas in the discharge region after each pulse.

3.1.1 WINDVAN and SCALE Laser Heads Compared

The similarities and changes in the laser mechanical features in going from the WINDVAN Configuration to the upgraded Transmitter can be seen by comparing the cutaway view of the WV shown in Figure 3.1-1 and the wire frame view of the SCALE subsystem shown Figure 3.1-2.

The laser head and compact flow loop assembly are almost identical in each subsystem. This is important in achieving maximum carryover since the discharge and flow technology incorporated in this component is responsible for most of the success of the WV design and represents the largest contribution to the development cost of that device. The most significant difference in the two are in the containers which house the electrical components that drive the laser.



MSNW · NOAA CO_2 LIDAR LASER

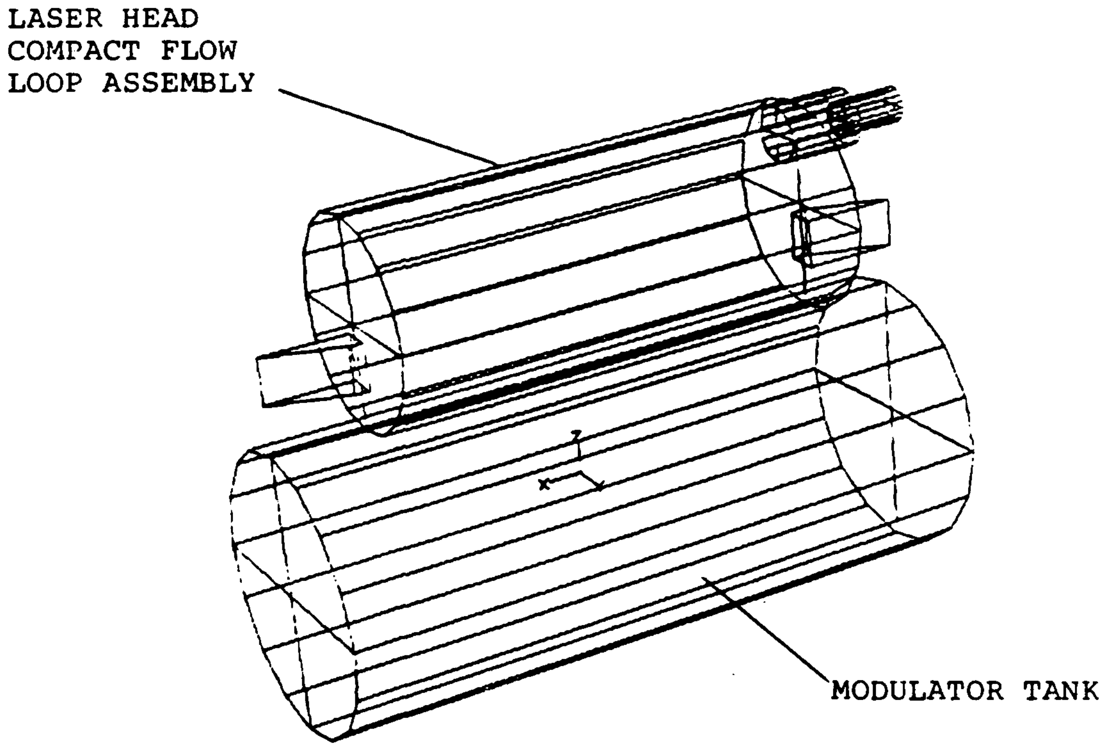


Figure 3.1-2. SCALE Laser Mechanical Configuration

The WINDVAN power supply and modulator are packaged in separate, rectangular, approximately equal volume tanks one of which is shown in Figure 3.1-1. In the SCALE design these components can be housed in a single cylindrical enclosure with a volume as indicated in Figure 3.1-2. The primary mechanical requirements imposed by the mission on the subsystem are the need to maintain the pressure and vacuum integrity and the need to withstand the vibration and loads during launch and maneuver. The sealed, domed end containers in the SCALE design satisfy the former and the packaging of the power supply and modulator discussed in the below in the laser electrical section satisfies the latter.

3.1.2 Criticalities, Mechanical Requirements

Table 3.1-2 gives the list of mechanical components shown in relation to the mission and shuttle design environment. Particular sensitivity of a component is denoted by a dot in the matrix and calls attention to the need for a data base and appropriate testing to certify the design approach selected.

3.1.3 Mechanical Risks

As can be seen from Table 3.1-3, the magnitude of the risk scores for the components of the mechanical system indicate that there are no serious issues associated with hardening the system for space. This is because all of the components have a space rated equivalent or a design data base from which space qualified version can be engineered.

Since the laser mechanical system is composed of an array of parts in a relatively high-Q configuration, a mass model of the system will reveal resonances in the bandwidth of the launch vibration spectrum. A modal analysis test to verify these predictions would be expected as part of the normal qualification process.

Table 3.1-2

CRITICALITY OF EQUIPMENT TO DESIGN ENVIRONMENTS

SUBSYSTEM: Laser (Mechanical)

ITEM	DESIGN ENVIRONMENTS: THERMAL VACUUM	THERMAL CYCLE	SINE VIBRATION	RANDOM VIBRATION	ACOUSTIC NOISE	PYROSHOCK	ACCELERATION	HUMIDITY	PRESSURE	LEAKAGE	CHEMICAL CORROSION	SHOCK VIBRATION	FLOW	HIGH VOLTAGE	EMP
1 FAN/DRIVE	o	o	o	o		o	o				o	o	o		
Transverse Fan			o	o		o	o				o				
Bearing/Ferro Labyrinth Seal			o	o		o	o				o	o	o		
Drive Shaft Coupling	o	o									o				
Fan Motor			o	o		o	o					o			
Magnetic Coupling			o	o		o	o					o			
2 FLOW LINER			o	o	o	o					o		o		
3 LASER HEAD (MECH.)	o	o	o	o	o	o	o		o		o	o	o		
Ground Electrode											o		o		
HV Electrode		o	o	o		o	o				o	o			
Laser Head Flange	o	o							o	o	o				
4 PRESSURE SHELL	o	o							o	o	o		o		
Outer Shell	o	o							o	o	o		o		
End Flanges	o	o							o	o	o		o		
5 WINDOW ASSEMBLY															
Gas Circulator	o	o	o	o		o	o		o	o	o	o	o		
6 HEAT EXCHANGER			o	o		o	o			o	o	o	o		
7 CORONA X-RAY PREIONIZER WINDOW	o	o			o				o	o	o		o		

LASER MECHANICAL COMPONENT RISK ASSESSMENT

NATURE OF DEVELOPMENT		SUPPORTING ANALYSIS/DATA		FUNCTIONAL CRITICALITY		TOTAL
ITEM Fan Drive	VALUE		VALUE		VALUE	
CATEGORY 4	2	CATEGORY 4	1	CATEGORY 1	3	6
ITEM Flow Liner						
CATEGORY 4	2	4	1	1	3	6
ITEM Laser Head						
CATEGORY 4	2	4	1	1	3	6
ITEM Pressure Shell						
CATEGORY 4	2	4	1	1	3	6
ITEM Window Assembly						
CATEGORY 4	2	4	1	1	3	6
ITEM Heat Exchanger						
CATEGORY 4	2	4	1	1	3	6
ITEM Preionizer						
CATEGORY 3	4	3	2	1	3	24

3.1.4 Mechanical Requirements Summary

A summary of the weights, volumes and power requirement is given for each of the components in the mechanical system in Table 3.1-4. The weight of the pressure shell, the heaviest component, includes the weight of the electrical components and insulating fluid contained within.

3.2 SCALE POWER MODULATOR

The purpose of the SCALE power modulator is to condition raw dc power and make it useful for operating the laser. Figure 3.2-1 shows the overall power modulator block diagram. A low voltage dc power bus feeds a dc/dc converter that charges a low voltage pulse-forming network (PFN). A solid-state switch then switches the energy stored on the PFN into the primary of the high voltage pulse transformer which, in turn, energizes the laserhead. The executive computer controls the trigger assemblies for optimum circuit performance and efficiency.

3.2.1 Laser Electrical System

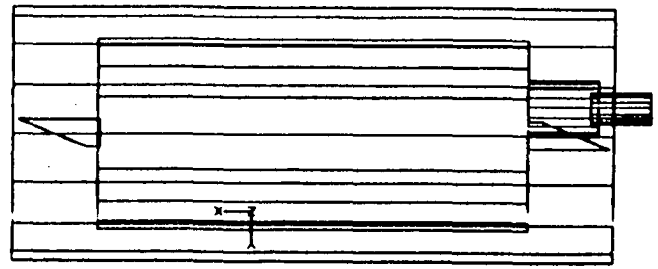
Figure 3.2-2 illustrates major components in the power modulator circuit topology and their associated timing waveforms. The dc/dc converter initially takes the input power bus voltage (approximately 200 V) and charges the PFN to 3 kV in about 1 ms. Once this is completed, the converter is turned off and the solid-state switch is fired, which introduces a 30 kV pulse across the laserhead. This causes the head avalanche and breakdown, and the laser gas then supports a 15 kV, 800 A power pulse for approximately 3 μS. The PFN determines both the pulse shape and pulse duration of the power pulse.

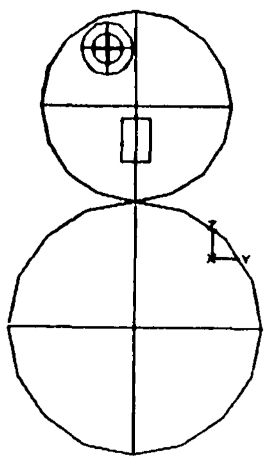
The solid-state switch identified for the modulator is the Westinghouse RBDT (Reverse Blocking Diode Thyristor), which has seen extensive field service in FAA radar systems.[(1)] The switching requirements for SCALE have been matched fairly closely to published radar

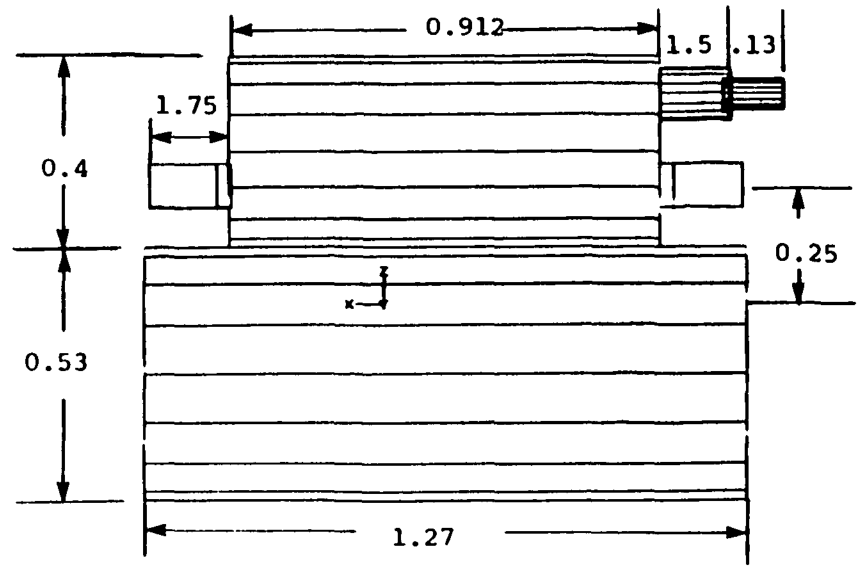
Table 3.1-4

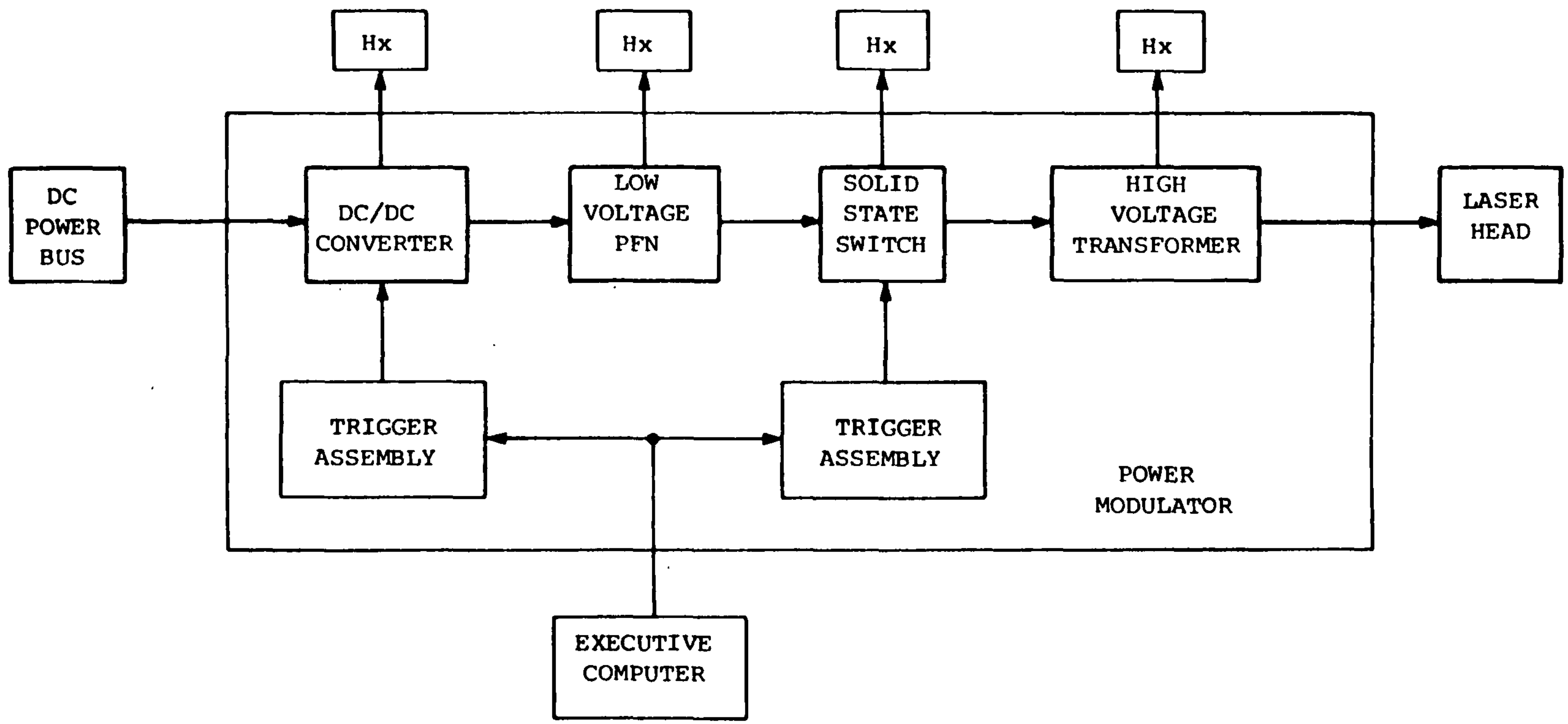
LASER (MECHANICAL) REQUIREMENTS SUMMARY

COMPONENT	POWER (W)	WEIGHT (kG)	VOLUME (kG)
1 Fan/Driver	75	5	0.030
2 Flow Liner	--	7	--
3 Laser Head/ Feedthrough	--	10	0.030
4 Pressure Shell	--	80	0.94
5 Window Assembly	--	5	0.60
6 Heat Exchanger	--	8	--
7 Corona Preionizer	--	10	0.015









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- Power Modulator all Solid State.
- Laserhead Driven by a High Voltage Transformer Which Allows Electronics to Operate at Relatively Low Voltages.
- Except at the Laserhead, Voltages in Modulator Tank will not Exceed 3 kV.
- Solid-State Switches are RBDTs.

Figure 3.2-1. Power Modulator Block Diagram

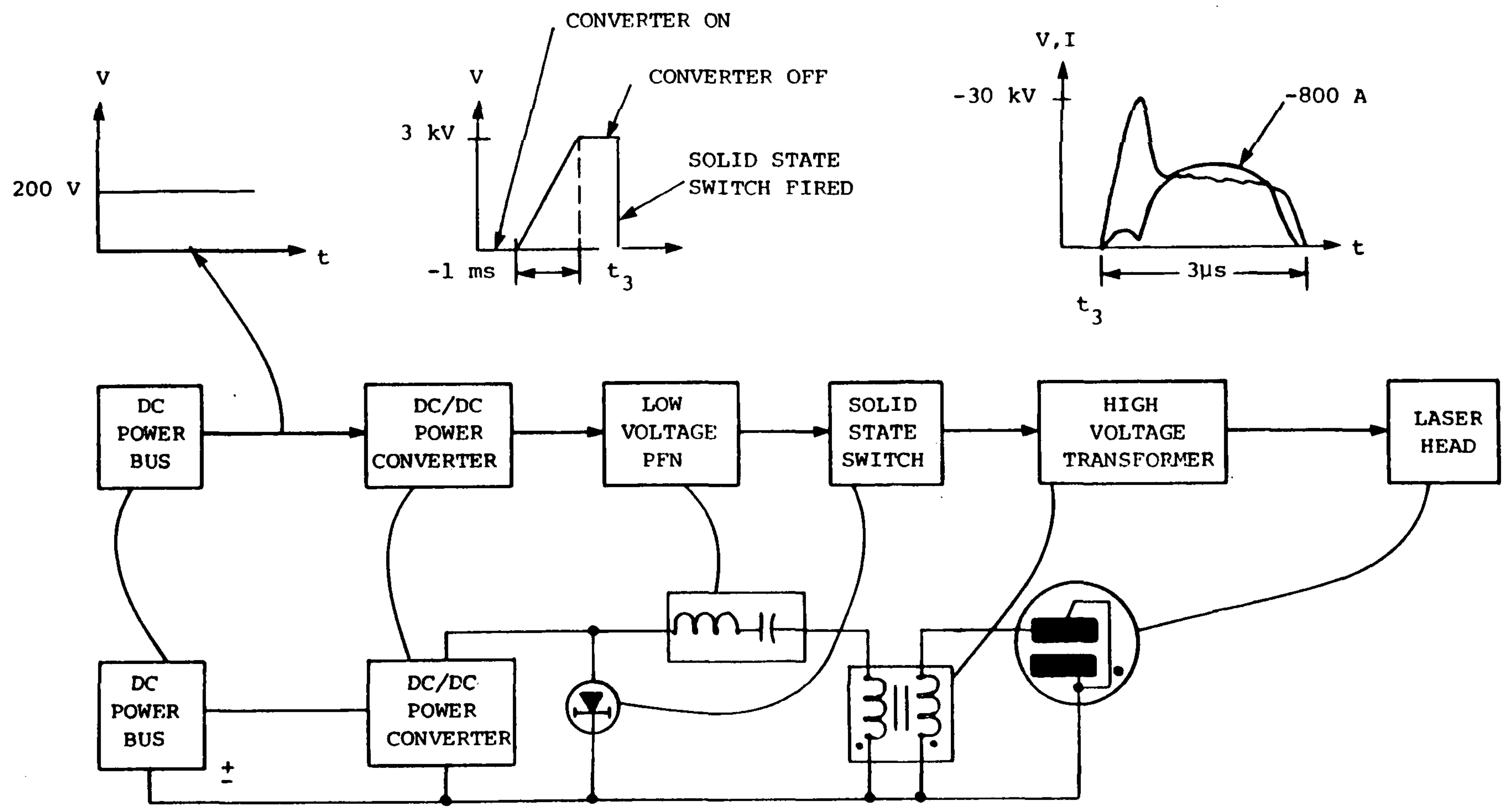

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Figure 3.2-2. Power Modulator Circuit Topology

requirements, so we see no real risk in incorporating the RBDTs into the laser system. The high voltage transformer technology is well understood and should pose no special problems.

An efficiency flowchart for the SCALE power modulator is shown in Figure 3.2-3. Working back from the laserhead, which requires 1750 W of power at 50 Hz, we have estimated the component efficiencies to be:

COMPONENT	**EFFICIENCY**
High Voltage Transformer	90%
Solid-state Switch	90%
PFN	95%
DC/DC Converter	90%
TOTAL Modulator Efficiency	**68%**

For a 68 percent efficient modulator, power requirements at the input dc power bus are 2600 W at 50 Hz, and 750 W must be removed by active cooling.

3.2.2 Comparison of WINDVAN and SCALE

The SCALE power modulator differs from the existing WINDVAN modulator in that SCALE will use solid-state switches whereas WINDVAN uses thyratrons. (Thyratrons are low pressure gas switches that require a substantial amount of auxiliary heater power.) Table 3.2-1 compares the two modulators. The principal advantages of SCALE over WINDVAN are overall system efficiency due to reduced auxiliary power requirements and size and weight. The proposed dc/dc converter for SCALE is substantially smaller and lighter than the WINDVAN power supply. We expect the SCALE modulator to require one-third less power and to be one-third smaller and lighter than WINDVAN. Figure 3.2-4 shows an overall drawing of the SCALE laserhead/modulator assembly, and Table 3.2-2 tabulates the power modulator requirements on the spacecraft.

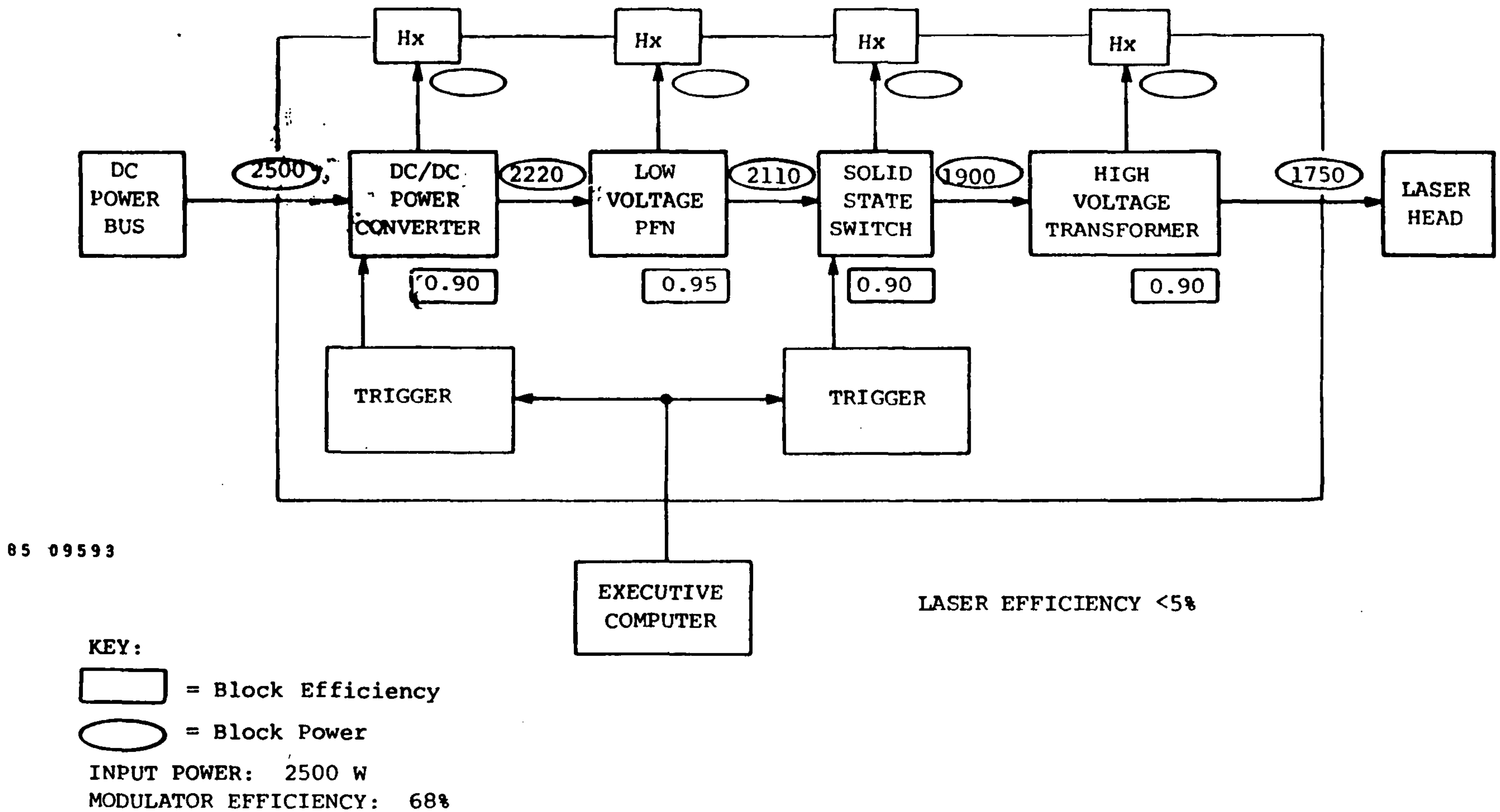
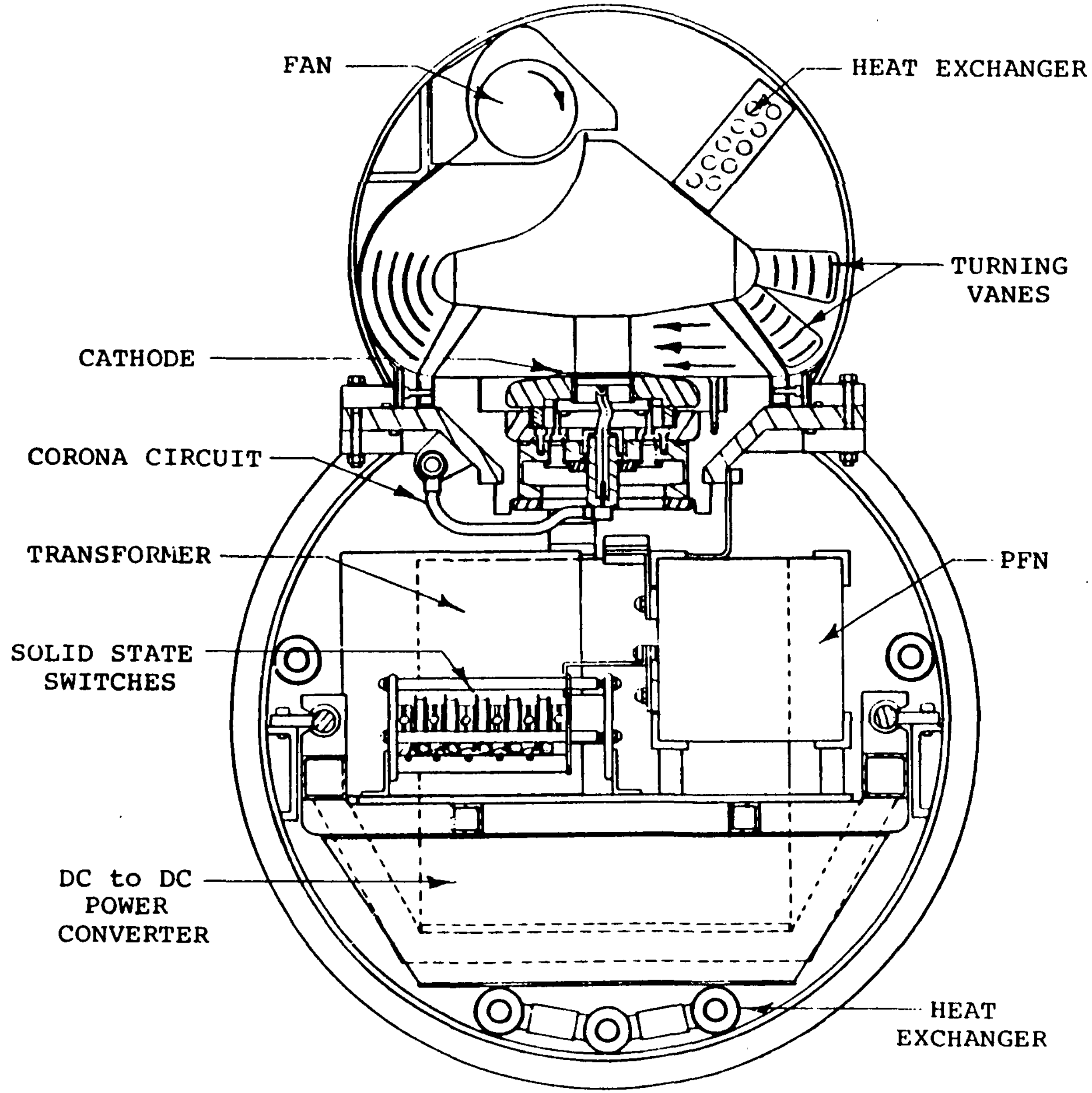


Figure 3.2-3. Power Modulator Efficiency

Table 3.2-1

POWER MODULATOR COMPARISONS

CATEGORY	NASA CO_2	WINDVAN
Switches	Solid-State RBDTs	2 Thyratrons
Transformers	1	1
Charging Inductors	–	1
Power Supply	DC/DC Converter	Standard Lab Supply
Trigger Assemblies	2	2
PFN	1	1
Auxiliary Heater Power	–	800 W
Overall Power Requirements @ 50 Hz	2.5 kVA	3.3 kVA
Volume	1.4 m^3	0.2 m^3
Weight (with oil)	1500 lb_m	2200 lb_m



LASER

WEIGHT-≈495 lbs
VOLUME-≈4.4 ft^3
(16" dia x 38" lg)

MODULATOR

WEIGHT-≈1000 lbs.
VOLUME-≈8.5 ft^3
(22" dia x 38" lg)

Figure 3.2-4. Laser Head/Modulator

Table 3.2-2

POWER MODULATOR SPACECRAFT REQUIREMENTS

Input Power	2500 W at 200 VDC
Output Power (to laserhead)	1750 W
Power Dissipated in Modulator	750 W
Modulator Volume	0.3 m^3
Modulator Weight	455 kG

3.2.3 Risk Assessment

Even though the SCALE modulator is smaller and more efficient than WINDVAN, it should offer no more risk than the WINDVAN approach. Table 3.2-3 gives the sensitivity of the power modulator to the design environment. Table 3.2-4 shows the risk associated with the modulator components. Table 3.2-5 gives the risk assessment for the SCALE modulator. The solid-state switch in SCALE poses a certain amount of risk in implementing the system; however, because RBDTs consume 800 W less power and are less sensitive to vibration and shock damage than are thyratrons and because thyratrons have not been space-qualified, we have rated the risk of thyratrons and RBDTs as being the same. Other circuit aspects of the two modulators are essentially identical.

The power modulator will be subjected to various types of shocks and vibrations during its mission life. Possible causes of failure are listed in Table 3.2-5, along with modulator sections that are exposed to these dangers. The detailed SCALE design must address the different operating environments; however, a major portion of these design problems have been successfully addressed by WINDVAN, and we feel confident that the upgraded SCALE modulator design will satisfy all requirements placed on it.

3.3 LASER THERMAL

The laser thermal system must insure that the temperatures of the laser medium, the laser modulator and the peripheral equipment on the pallet are maintained within the desired limits.

Table 3.2-3

CRITICALITY OF EQUIPMENT TO DESIGN ENVIRONMENT

SUBSYSTEM:
Power Modulator

ITEM	THERMAL VACUUM	THERMAL CYCLE	SINE VIBRATION	RANDOM VIBRATION	ACOUSTIC NOISE	PYROSHOCK	ACCELERATION	HUMIDITY	PRESSURE	LEAKAGE	CHEMICAL CORROSION	SHOCK VIBRATION	FLOW	HIGH VOLTAGE	EMP
DC/DC Converter		o	o	o		o	o				o	o		o	o
Low Voltage PFN		o	o	o		o	o			o	o	o		o	
Solid State Switch		o	o	o		o	o				o	o		o	o
High Voltage Transformer		o	o	o		o	o				o	o		o	
Trigger Assemblies		o	o	o		o	o				o	o		o	o

Table 3.2-4

SUBSYSTEM: Power Modulator

POWER MODULATOR COMPONENT RISK ASSESSMENT

NATURE OF DEVELOPMENT		SUPPORTING ANALYSIS/DATA		FUNCTIONAL CRITICALITY		TOTAL
ITEM DC/DC CONVERTER	VALUE		VALUE		VALUE	
CATEGORY 3	4	CATEGORY 3	2	CATEGORY 1	3	24
ITEM LOW VOLTAGE PFN						
CATEGORY 4	2	4	1	1	3	6
ITEM SOLID STATE SWITCH						
CATEGORY 3	4	3	2	1	3	24
ITEM HIGH VOLTAGE TRANSFORMER						
CATEGORY 4	2	4	1	1	3	6
ITEM TRIGGER ASSEMBLIES						
CATEGORY 4	2	4	1	1	3	6
ITEM						
CATEGORY						
ITEM						
CATEGORY						

Table 3.2-5

POWER MODULATOR RISK/ASSESSMENT

CATEGORY	NASA CO_2	WINDVAN
DC/DC Converter	24	24
PFN	6	6
Switches	24	24
High Voltage Transformer	6	6
Trigger Assemblies	6	6
	36	36

Since risk scores are identical, focus on solid-state modulator approach. Reasons for this:

- o Solid-state approach consumes 800 W less power
- o Solid-state approach less sensitive to vibrational/shock damage
- o Packaging will be smaller than for thyratron version
- o Thyratrons have not been space-qualified

3.3.1 Thermal Requirements

Table 3.3-1 lists the important temperatures and heat fluxes for the transmitter. The effect of temperature on the laser output is shown in Figure 3.3-1. A temperature ten degrees above the maximum coolant inlet temperature can result in a 15 percent decrease in transmitter efficiency. To insure that this temperature is minimized the laser head and flow loop are located nearest to the coolant inlet port in the payload flow loop.

3.3.2 Thermal System

Figure 3.3-2 showns the thermal schematic of a system. The system consists of three flow loops the primary one being the orbiter cargo bay loop which addresses the pallet as well as all the other actively cooled equipment installed in the bay. The Experimental Equipment loop,addresses the apparatus requiring direct liquid cooling. The interface between the two is the Payload loop which provides the isolation necessary for safety and for convenience during preflight testing. The Payload loop also addresses equipment which is normally part of the ESA pallet including the igloo and the pallet cold plates. The interface between the Payload loop and the experiment is through the Experiment heat exchanger. This component is normally used on the ESA module but may be adapted for use on the pallet thus permitting the use of a space qualified unit at this important interface. The other important item that can be directly utilized from the list of space qualified equipment is the freon pump package. Two identical units are indicated in Figure 3.3-2. The unit is shown in detail in Figure 3.3-3. The capacity of this unit matches well with the 3150w heat load in the experiment loop.

Equipment for the thermal system can thus be divided into two major groups; the first includes that of a general purpose nature that can be selected from an array of existing space qualified equipment and as such can be expected to meet most or all of the mission requirements without modification. The second group which includes the experiment specific

Table 3.3-1

TRANSMITTER TEMPERATURS AND HEAT FLUXES

Heat Deposited Flow Loop From Discharge		1650 W
Heat Deposited in Modulator		750 W
Auxiliary Payload Heat Load		750 W
	Total	3150 W
Maximum Orbiter Bay Coolant Inlet Temperature		38 °C

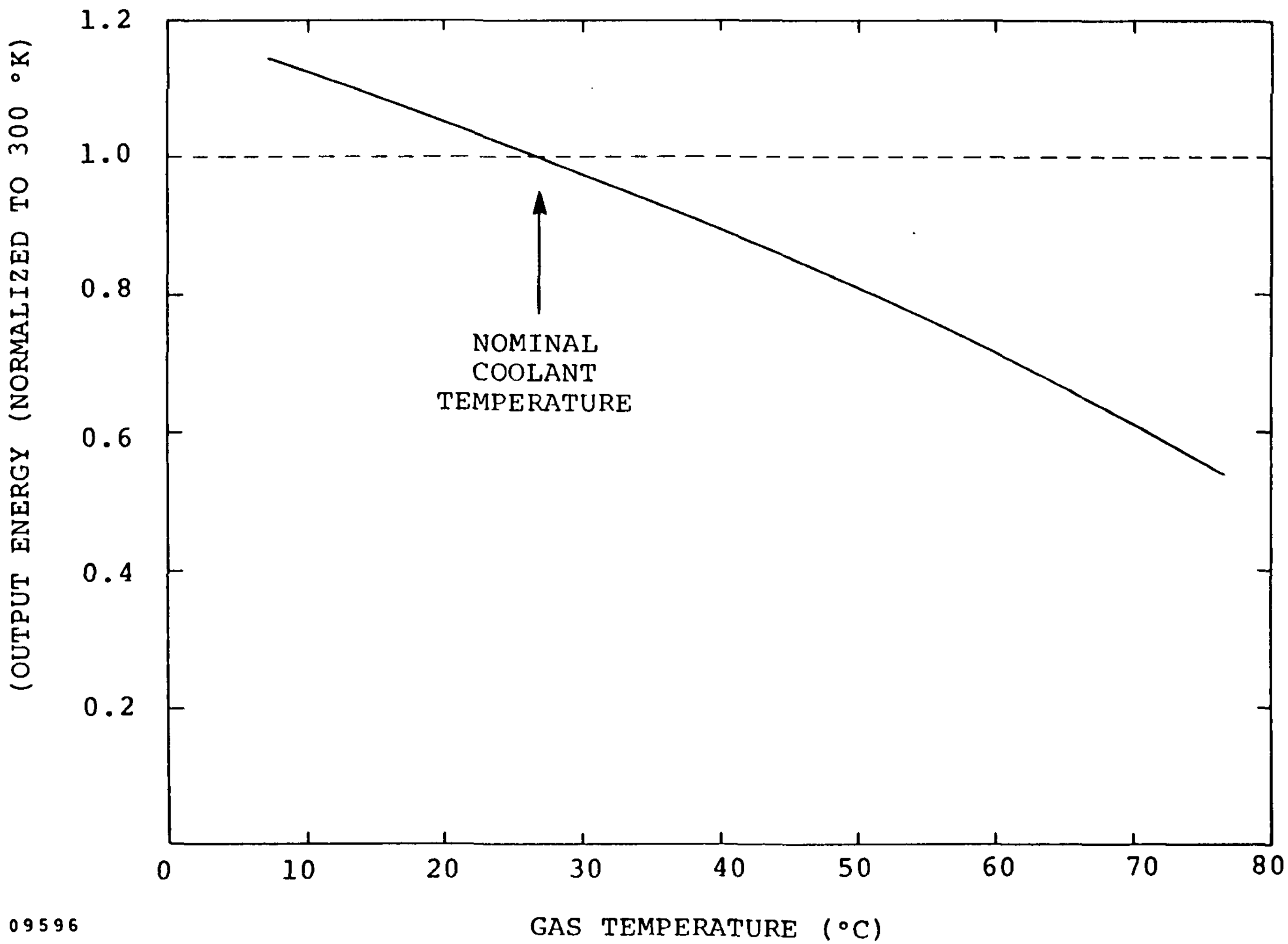
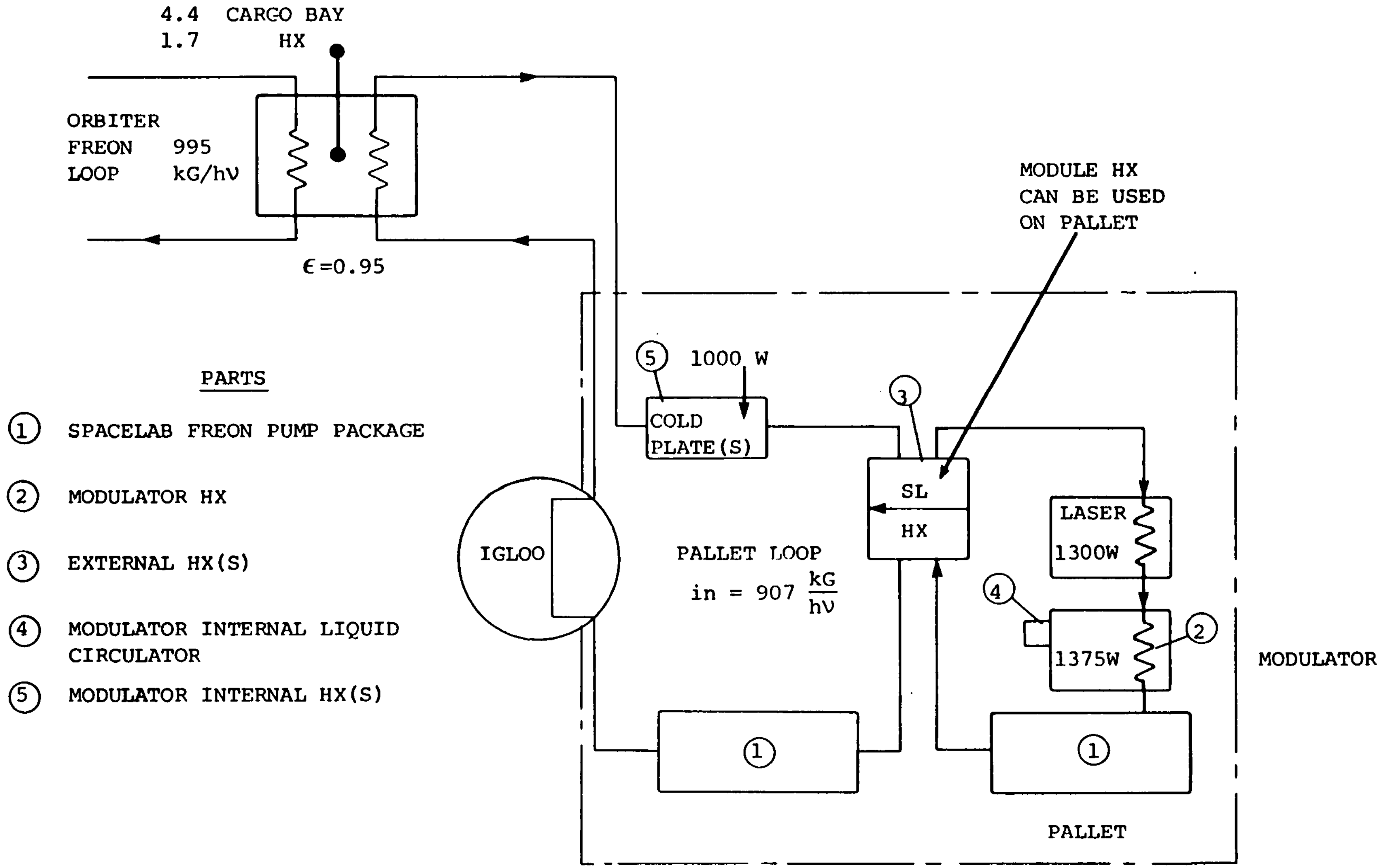
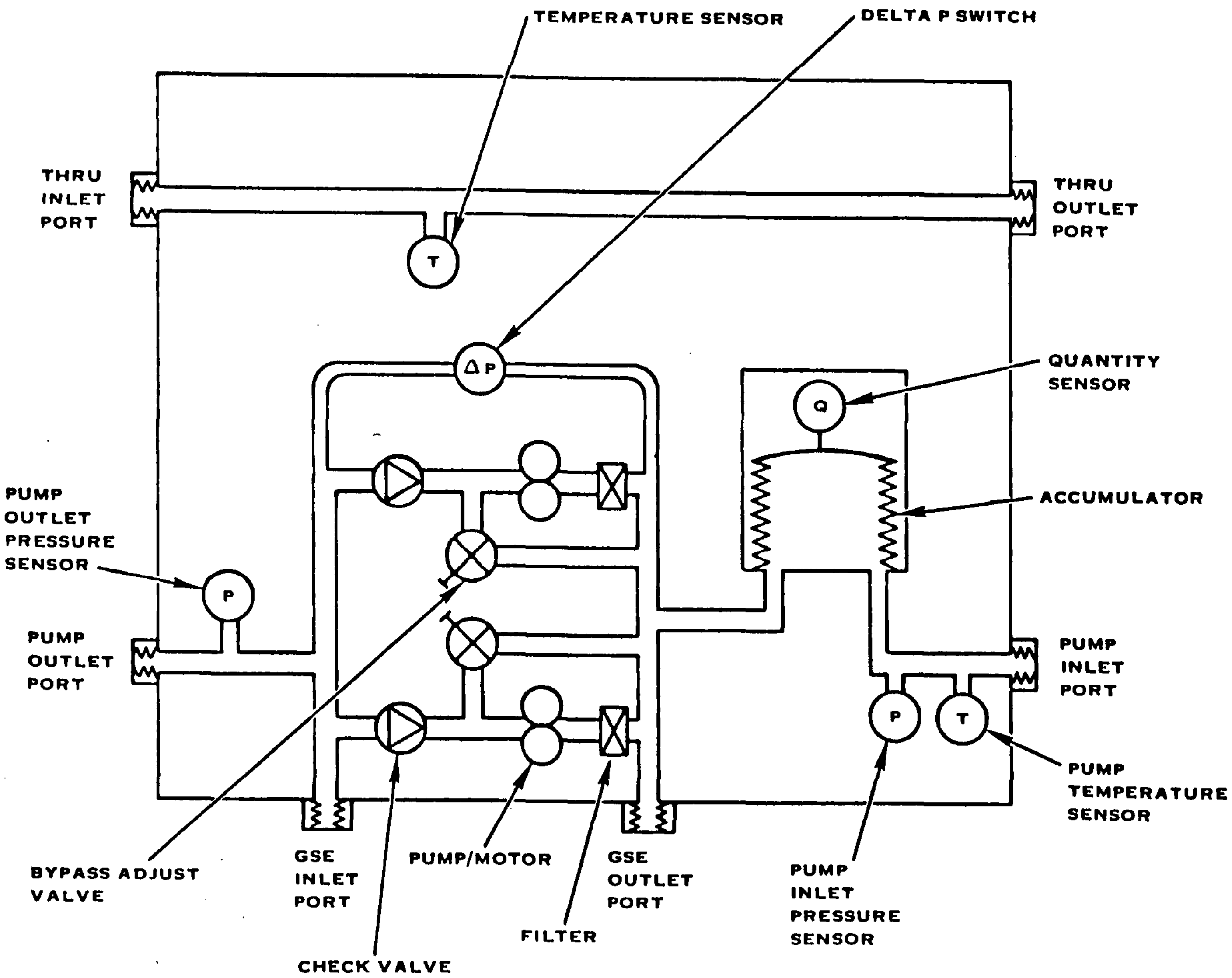


Figure 3.3-1. Effect of Temperature on Laser Output.



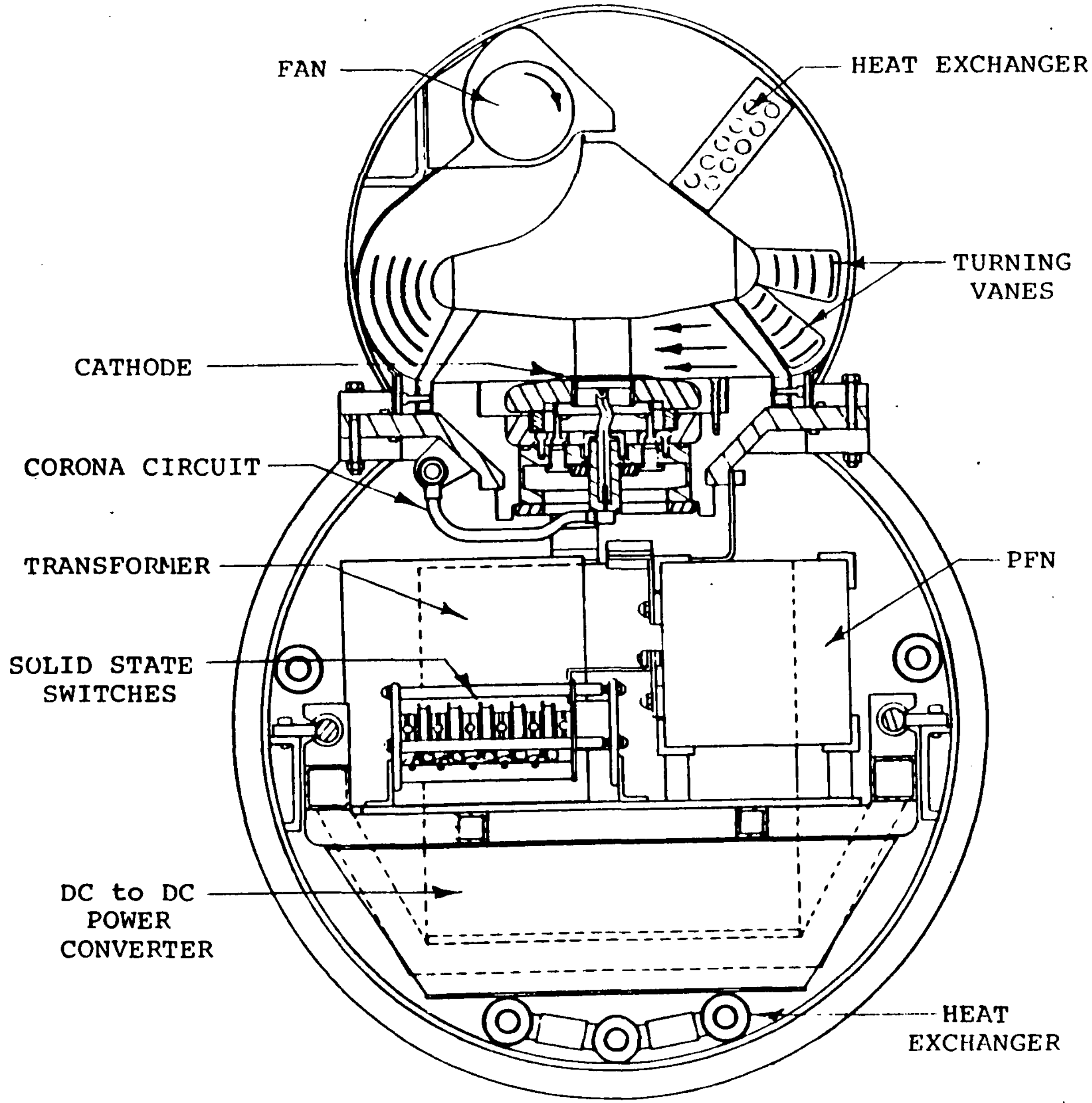
85 09868

Figure 3.3-2. Thermal System (PC5-6) Environmental Control HB



HAMILTON STANDARD   Figure 3.3-3. Spacelab Freon Pump Package Schematic.

equipment. In this latter category are the laser flow loop fan and heat exchanger and the modulator heat exchanger and pumps or fans. From a thermal point of view the laser head flow loop configuration has been engineered to insure that proper forced convection heat transfer is achieved. The heat transfer requirements imposed by the laser performance in the existing WINDVAN device are as stringent as those introduced by the orbiter mission. This is not the case with the modulator cooling. The mechanical and electrical requirements for this subsystem were discussed above and the configuration to meet these has been shown. The thermal requirements for this component, shown in Figure 3.3-4, are likely to be the ones which dominate and which will determine cost and complexity. Figure 3.3-5 shows schematically the four configurations considered for providing cooling to the modulator. The gas version shown in the upper right hand corner is exactly analogous to the laser head flow loop configuration. It involves circulating an electrically insulting coolant gas such as nitrogen or sulfur hexafluoride in a pressurized container. Modulator components would have to be configured in a way which would insure that fresh coolant gas is circulated everywhere throughout the modulator package prevent the buildup contaminants in regions of high electric field stress. The gas/liquid approach is a variation of the gas only version in which the liquid from payload loop is circulated through additional coldplates within the modulator to remove heat from subcomponents generating significant heat. The success of this approach again depends upon providing forced convection throughout the container. The liquid approach uses the payload coolant to address the concentrated heat sources with direct irrigation and the diffuse ones with a parallel flow reaching the rest of the container. The liquid/liquid approach attempts to accomplish the same result but with the addition of an extra pump and heat exchanger the designer is given the choice of coolant/electrical insulator. This may be important for longer missions where liquid degradation may be an issue. For the modest 2×10^7 shot life requirements of the SCALE mission, coolant life is unlikely to be a problem. Some of the other important considerations in the selection of a modulator cooling approach are listed in Table 3.3-2. The selection of one



LASER

WEIGHT-≈495 lbs
VOLUME-≈4.4 ft^3
(16" dia x 38" lg)

MODULATOR

WEIGHT-≈1000 lbs.
VOLUME-≈8.5 ft^3
(22" dia x 38" lg)

Figure 3.3-4. Laser Head/Modulator.

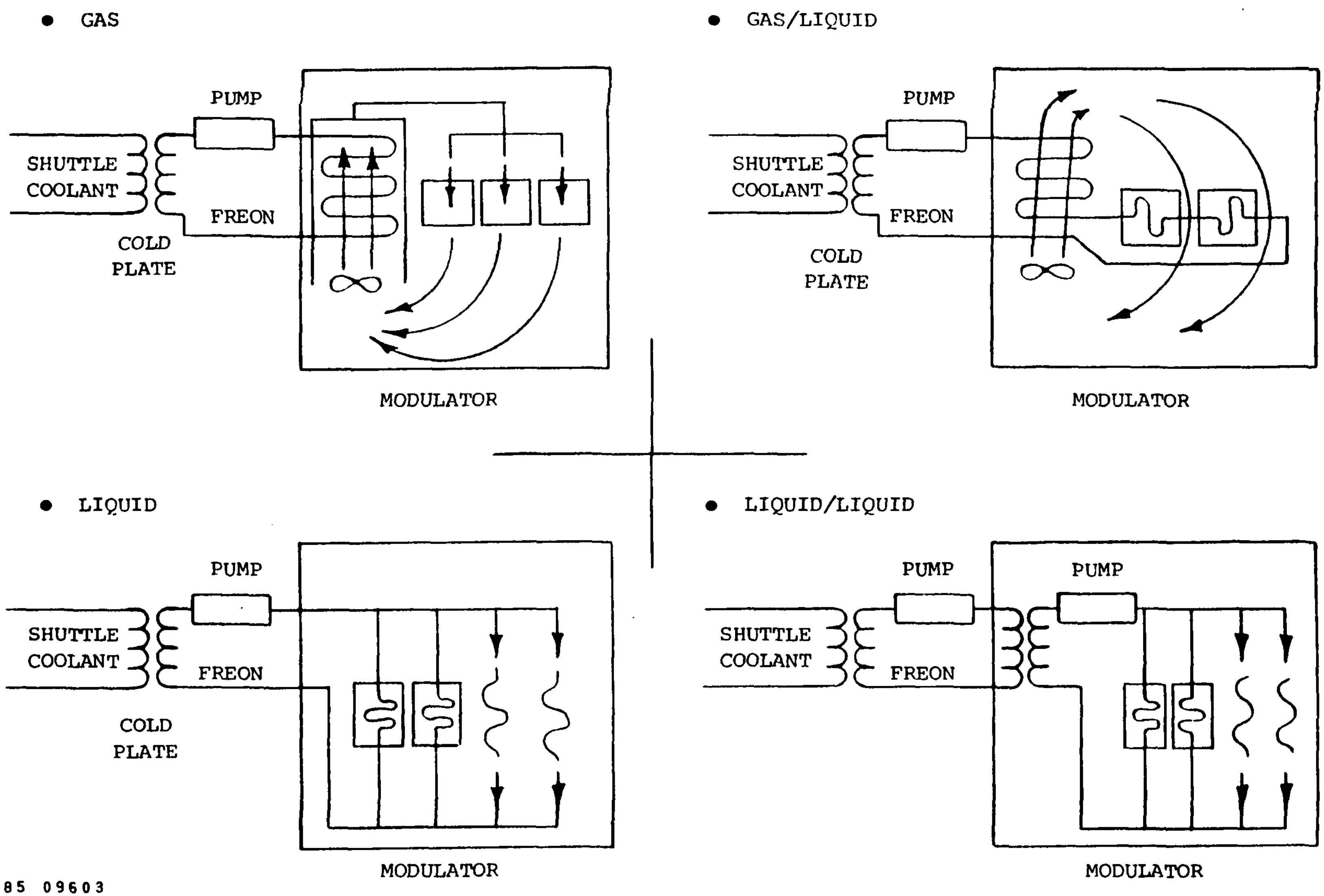


Figure 3.3-5. Modulator Thermal Control.

Table 3.3-2

MODULATOR INSULATOR/COOLING MEDIUM

GAS

- Clean
- Pressurized Modulator Tank
- Gas Flow Through Ducting
- Poor Thermal Capacity
- Poor Thermal Transfer (Large Hx)

GAS/LIQUID

- Clean
- Pressurized Modulator Tank
- Some Components Directly Cooled
- Some Components Gas Cooled
- Better Thermal Management of High Power Components

LIQUID

- Modulator Components Must be Impregnated With Insulating Fluid (Evacuable)
- Good Thermal Capacity
- Good Thermal Transfer (Compact Hx)
- Incompressible Fluid
- Weight May be Greater Than Gas Filled

LIQUID/LIQUID

- Same as Liquid
- Overall Cooling Efficiency Lower
- Modulator Sealed and Self Contained, Needing Only External Cooling Connection

of these approaches will be made after detailed trades during the preliminary design phase.

3.3.3 Criticalities in Thermal System

The first column of Table 3.3-3 lists the thermal system components. The remaining columns of that figure list the environments which are presented to those components during the flight. Components which are sensitive to those environments are flagged in the matrix and as such must be scrutinized during the design and qualification phases to insure that the requirements imposed by the mission on the equipment are met.

3.3.4 Risk Assessment

Table 3.3-4 gives a list of components rated according to the risk assessment scheme presented earlier. The division for risk is by the same catagories delineated above the components with heritage rate as minimal and the experiment specific components indicate the need for risk reduction measures including further design as well as qualification testing. Qualification testing will be required for the modulator the be sure that a forced convection cooling regime is maintained throughout the modulator shell. This will be accomplished by probing the flow field within the modulator as well as measuring the temperatures at strategic locations on internal surfaces.

Summarizing the thermal system design approach: a conservative design approach satisfies mission requirements using a maximum number of space qualified components. Risks are isolated in the modulator where the design has been scoped to the level where it can be stated that this component presents a design problem which is inherently less difficult than the head and flow loop and as such requires a less arduous development effort. Since no design verification tests were required for the thermal aspect of the WINDVAN development program none are anticipated for the modulator packaging.

Table 3.3-3

CRITICALITY OF EQUIPMENT TO DESIGN ENVIRONMENT

SUBSYSTEM: Thermal ITEM	THERMAL VACUUM	THERMAL CYCLE	SINE VIBRATION	RANDOM VIBRATION	ACOUSTIC NOISE	PYROSHOCK	ACCELERATION	HUMIDITY	PRESSURE	LEAKAGE	CHEMICAL CORROSION	SHOCK VIBRATION	FLOW	HIGH VOLTAGE	EMP
Freon Pump Package		o	o	o			o		o	o		o			
Experiment Heat Exchanger		o	o	o	o	o	o		o	o		o	o		
Laser Heat Exchanger		o	o	o	o	o	o		o	o		o	o		
Modulator Heat Exchanger		o	o	o	o	o	o		o	o		o	o		
Modulator Pump		o	o	o			o		o	o		o			
Modulator Flow Dueting		o	o	o	o	o	o						o		

Table 3.3-4

THERMAL COMPONENT RISK ASSESSMENT

SUBSYSTEMS: Thermal

NATURE OF DEVELOPMENT		SUPPORTING ANALYSIS/DATA		FUNCTIONAL CRITICALITY		TOTAL
ITEM	VALUE		VALUE		VALUE	
CATEGORY		CATEGORY		CATEGORY		
ITEM FREON PUMP PACKAGE						
CATEGORY 5	1	4	1	1	3	3
ITEM EXPERIMENT HEAT EXCHANGER						
CATEGORY 5	1	4	1	1	3	3
ITEM LASER HEAT EXCHANGER						
CATEGORY 4	2	4	1	1	3	6
ITEM MODULATOR HEAT EXCHANGER						
CATEGORY 4	2	4	1	1	3	6
ITEM MODULATOR PUMP						
CATEGORY 5	1	4	1	1	3	3
ITEM MODULATOR FLOW DUCTING						
CATEGORY 3	4	3	2	1	3	18

3.4 LASER GAS REGENERATION

The gas lifetime for pulsed, self-sustained discharge CO_2 lasers is limited by the dissociation of CO_2 to form CO and O_2

$$CO_2 \rightarrow CO + 1/2\ O_2$$

Even more important than the loss of the lasing species itself is the gradual buildup of small quantities of O_2 in the gas, which increases the tendency for arc formation. The gas lifetime can be extended by adding small amounts of CO and/or H_2 to the gas mixture in order to force the equilibrium back towards CO_2. However, even with the addition of CO and H_2, the gas mixture must be continually renewed in order to maintain arc free performance. For most applications this is accomplished by slowly flowing new gas into the laser and simply throwing away the old gas. For operation with isotopically selected CO_2 or for space applications where it is not practical or economical to dump the old gas, a catalyst must be employed to reform CO_2.

For purposes of this study three gas make up approaches were considered: Catalytic regeneration, disposal by recompression and storage and finally disposal by jettisoning directly overboard. The last two approaches require a sufficient storage capacity to complete the entire mission. The CO_2 regeneration requirements are shown in Table 3.4-1 for a 3×10^7 shot mission. Regeneration, is the most difficult approach, so it was studied in the greatest detail to provide a conservative baseline. Jettisoning is the simplest approach, and the storage requirements for a 5 day mission are modest. Concerns about contamination of the orbiter bay with spent laser gas must be viewed in context of the 36 pounds of propellant required per 2 minutes yaw maneuver per orbit to maintain the proper ground track for the SCALE mission.

Unless some unforseen requirement surfaces requiring a closed system, overboard dumping with bottle recharge offers a simple and effective choice for gas utilization.

Table 3.4-1

CO_2 GAS REGENERATION REQUIREMENTS

CO_2 Dissociation $\tilde{<} 2 \times 10^{-3}$ Per Pulse

O_2 Production Rate = 1.5 ℓ-Torr/sec at 50 Hz

For Arc Free Performance XO_2 $\tilde{<} 5 \times 10^{-3}$

Therefore ~0.5% of Main Flow Must be Cleaned Up
For a Discharge Flush Factor of 4

The simplest way to clean up the gas is to flow fresh gas into the laser flow loop and dump the spent gas overboard. Based on the clean up rate of 2ℓ/sec calculated above, 4 x 10^5 ℓ of gas would be required for 10^7 shots. This requirement can be reduced by adding CO and H_2 to the gas mixture. Our 0.5 J, 50 Hz CO_2 laser CDL-1 required a make-up flow of 10^{-2} ℓ/sec in order to maintain arc free performance. Scaling to Windvan volume and pressure, a flow of 0.35ℓ/sec would be required. This corresponds to a required gas inventory of 7000ℓ for 10^7 shots, which is quite manageable.

3.4.1 Catalytic Regeneration

The options available for catalyst material are shown in Table 3.4-2. Among the catalytic schemes reported for CO_2 regeneration are a hot Pt wire [2] (~1100°C), Pt on Al_2O_3,[3,4] Cu/CuO,[3,5] Hopcalite (60% MnO_2, 40% CuO, and trace quantities of other oxides), [6] and Pt or Pd/SnO_2.[5,7] Hopcalite is a commercially available catalyst and is used in the commercial CO_2 laser produced by Laser Sciences, Inc. It requires the addition of CO to the laser mix for proper operation, and it deteriorates after exposure to H_2O and must be periodically reactivated. Pt or Pd/SnO_2 is a more recent development and is not yet commercially available. However, Engelhard Industries has prepared custom samples for the group at NASA LARC and would presumably be willing to supply them to others.[8] The Pt or Pd/SnO_2 catalysts are approximately a factor of 100 more active than hopcalite and their operation is not degraded by H_2O, but is in fact enhanced.[9] The higher activity for Pt or Pd/SnO_2 means that catalyst can be operated at a lower temperature, which minimizes the amount of power required to heat up the gas flow. In fact, Stark et al. have used this catalyst directly in the main gas flow with the only heat being furnished by the discharge energy addition to the gas.[7]

Table 3.4-2
CATALYSTS FOR CO_2 REGENERATION

	Pt/SnO_2 or Pd/SnO_2	MnO_2/CuO (Hopcalite)
ADVANTAGES	• ~100 times more effective than Hopcalite → lower temperature • Not degraded by water • No bakeout	• Established cataloyst for $CO + 1/2\ O_2 \rightarrow CO_2$ • Demonstrated laser operation • Commercially available
DISADVANTAGES	• Not commerically available • Limited database • Packaging not demonstrated	• Poisoned by water • Effectiveness decays with time • Bakeout required • Lower effectivenss → higher temperature • Small CO addition required

In order to ensure arc free performance, the O_2 concentration must be kept $\lesssim 0.5$ percent.[7] The amount of CO_2 dissociation per pulse can be estimated from the measurements of Pace and Lacombe on a corona preionized CO_2 laser with approximately the same energy loading as for our Windvan Laser.[10] They found that there was essentially no reformation of CO_2 up to about 4000 pulses, at which time approximately 8 percent of the CO_2 had been dissociated. This number must be multiplied by the ratio of their total loop volume to the discharge volume ($\sim 5.6\ell/30\ cm^3 = 187$) and divided by the number of pulses to give a CO_2 dissociation rate of 0.36% per pulse in the discharge volume. The O_2 production rate is half of the CO_2 dissociation rate or 0.18% per pulse. For Windvan operation at 50 Hz and with 30 Torr CO_2, the estimated O_2 production rate is $\sim 1.8 \times 10^{-3} \times 30$ Torr $\times$ 50 Hz $\times$ 1ℓ/discharge volume = 2.7 Torrℓ/sec. To maintain the O_2 concentration at $5 \times 10^{-3} \times 300$ Torr = 1.5 Torr, a gas flow of approximately 2ℓ/sec must be cleaned of O_2. The flush factor for the main flow in Windvan is ~ 4, so that the volume flow rate is 50 Hz $\times$ 1ℓ $\times$ 4 = 200ℓ/sec. Thus approximately 1% of the main gas flow must have the O_2 removed in order to keep the O_2 concentration at a low enough level to permit arc free operation.

The catalytic oxidation of CO to reform CO_2 is shown schematically in Figure 3.4-1. A portion of the main gas flow is directed over the catalyst bed and then routed back through a heat exchanger to cool the gas. Depending on the amount of gas which must be cleaned, the catalyst can be located outside the main flow loop with its own fan or actually be inserted in the main gas flow loop without the need for a separate fan.[7] Locating the catalyst in the main flow loop minimizes the amount of ancillary equipment required. The catalyst would be heated by the hot gas from the discharge. If the catalyst can be coated onto some support plate and still maintain a large surface area without spreading dust all over the laser, then an array of plates can be placed in the main flow loop. The ratio of the length of the plates in the flow direction to the spacing perpendicular to the flow direction would be chosen to assure good contact of the gas with the catalyst, in a way similar to the design of heat

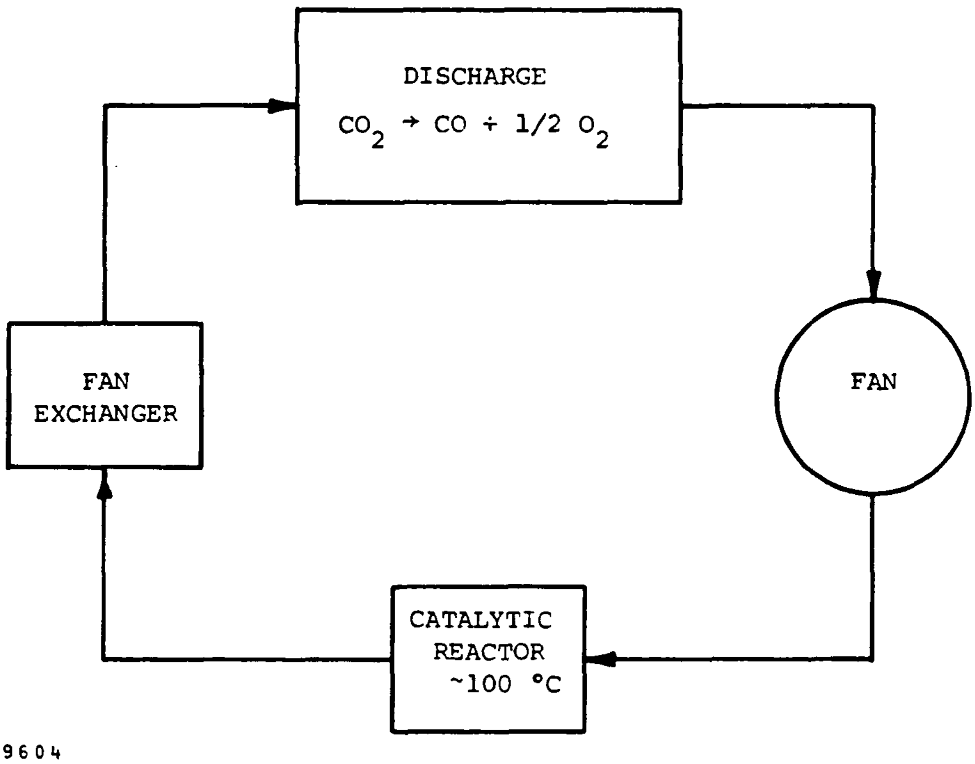


Figure 3.4-1. Catalytic Gas Regeneration System.

exchangers. The extra flow impedance would increase the fan power by about the same amount as the heat exchanger (~10% of the present flow power). Although operation of the catalyst in the main flow loop has been demonstrated,[7] no discussion was presented of how well the catalyst adhered to the mounting plates or how much dust was spread throughout the flow loop.

By placing the catalyst in an external loop, dust can be controlled with a particle filter at the expense of increased pressure drop. In addition, the catalyst temperature can be increased so that the required amount can be reduced. However, an extra fan is required along with its fan power and the extra heat to raise the gas temperature to the catalyst temperature. Because of the unresolved issue of encapsulating the catalyst without reducing its surface area, we have selected the external catalyst loop as our baseline approach. The layout is shown in Figure 3.4-2. A portion of the laser gas flow is extracted from the laser flow loop downstream of the discharge. The external fan circulates the gas through a counterflow heat exchanger and a heater to raise its temperature to the temperature of the catalyst bed (~100°C). The gas then passes through the catalyst bed to reoxidize CO and O_2, a filter to remove any dust, and then through the counterflow heat exchanger to be cooled before re-entering the main flow loop downstream of the transverse fan. A space qualified fan manufactured by Hamilton Standard (Model #SV755524) has been identified for this application. It can provide a volume flow rate of 100 at a lift of 3 in H_2O and requires an electrical input power of 180 W.

The weight of catalyst required can be estimated from the data of Stark and Harris[7] and from the data of Miller, et al.[11] Stark and Harris have measured a volumetric O_2 recombination rate of $\sim 3 \times 10^{-4}$ ℓ sec^{-1} g^{-1} at 40°C with an activation energy of 41.4 kJ/mole for Pt/SnO_2. Using this number together with the estimated O_2 production rate of 2.7 Torr ℓ/sec for Windvan gives a catalyst weight of 6 kG to keep the O_2 partial pressure below 1.5 Torr. This amount of catalyst can be reduced to ~0.5 kG by increasing the catalyst temperature to 100°C.

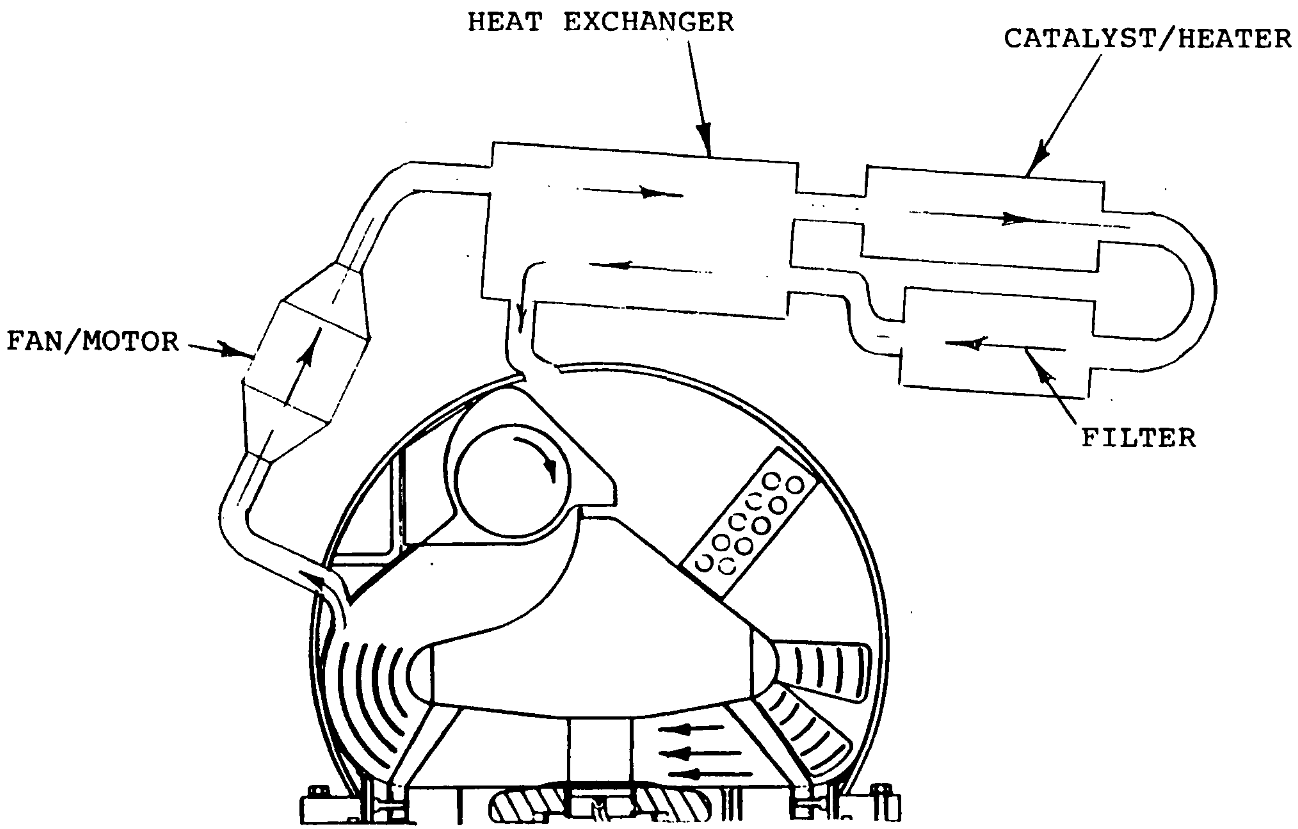


Figure 3.4-2. Gas Processor Configuration.

The results of Miller, et al.[11] give a different method for estimating the required weight of catalyst. They relate the weight of catalyst w to the contact time τ, the volume flow rate F, and the catalyst specific void volume V'_o according to

$$W = \frac{F \tau}{V'_o}$$

They have determined the catalyst specific void volume for Pt/SnO_2 to be $V_o = 0.374$ cm³/g and the required contact time for complete conversion of CO and O_2 to CO_2 to be ~1.5 sec at T = 100°C. For our required clean up flow rate of 1000 standard cm³/sec,

$$W = \frac{1000\ (1.5)}{0}.374 = 4 \text{ kG.}$$

This is considerably larger than the amount estimated from the Stark and Harris results scaled to the same temperature. These results are summarized in Table 3.4-3.

For operation with isotopically selected CO_2, the results of Hess, et al.[4] indicate isotopic scrambling from the SnO_2 catalyst component. Preliminary results indicate that this scrambling can be controlled by first reducing the catalyst surface with H_2 and then reoxidizing with $^{18}O_2$. However, the long term effectiveness of this treatment has not been demonstrated yet. Even if the surface treatment is not effective, the isotopic scrambling can be controlled by completely forming the SnO_2 from $^{18}O_2$, although the cost would be high for the estimated 4 kG of catalyst.

The work of Stark and Harris and Hess and co-workers indicate that Pt or Pd/SnO_2 is a very promising catalyst for closed cycle CO_2 lasers. The main remaining issues for our application are demonstration of long term operation for >10⁷ shots, demonstration of some method of encapsulating the catalyst without reducing its surface area, and control of the isotopic scrambling for use with rare isotope mixtures. Work on the development of

Table 3.4-3

AMOUNT OF CATALYST REQUIRED

AMOUNT OF CATALYST	
Scaling from LaRC results (T ~ 100°C)	220 g
Scaling from RSRE laser results (T ~ 40°C)	580 g
Scaling from RSRE reaction results (T ~ 40°C)	2250 g
Heater Power for 100°C Operation	10 W
Circulator Power	180 W

Pt/SnO_2 catalysts is continuing at NASA LaRC. In addition, the effectiveness of the catalyst could be tested at STI using our 50 Hz CDL-1 CO_2 laser to demonstrate operation for $>10^7$ shots while monitoring the O_2 concentration in the laser gas. This could be done either with an external catalyst loop or with the catalyst in the main laser flow loop and could also be used to investigate rare isotope mixtures. The CDL-1 laser is very similar to Windvan in that it is a corona preionized discharge laser with a 50 Hz repetition rate and transverse fan/compact flow loop configuration. However, the CDL-1 laser is considerably smaller and would minimize the amount of gas and catalyst required, as well as the time and cost for modifications. One of these laser systems is currently available at STI. The design database for the Pd or Pt/SnO_2 catalyst is given in Table 3.4-4.

3.5 OPTICAL/STRUCTURAL

3.5.1 WINDVAN Optical Configuration

The small optics which process the cw laser beams are straightforward. All of these optics are ZnSe components with appropriate coatings. The periscope which brings the IO beam down to table level also causes a polarization rotation, so that the two beams are in opposite polarizations as they cross the table. This fact is used to advantage in tuning the various beam intensities at the detectors. A beamsplitter picks off the IO sample for the lock detector. The sample is focused on the detector through a rotatable wire grid polarizer that is used to optimize the intensity.

A pair of beamsplitters picks off the samples of both beams needed by the IO/LO beat detector. These two beams are colinear after the second beamsplitter but have crossed polarizations. The combined beam is focused onto the beat detector through a pair of wire-grid polarizers. The first polarizer changes the ratio of the two beams presented to the detector, while the second (or its angle relative to the first) changes the total signal level.

Table 3.4-4

DATABASE FOR Pd or Pt/SnO_2 CATALYST

Start, et al. (RSRE) Demonstrated Control of XO_2 ~< 0.5% for 1.5 x 10^6 Shots at 20 Hz

- Catalyst located in main flow loop
- Temperature ~40°C

Hess, et al. LaRC) Demonstrated Control of XO_2 ~< 0.5% for 1.5 x 10^5 at 10 Hz

- Catalyst located in external flow loop
- Laser power ~90% initial power at 100°C

LaRC Preliminary Tests with $C^{18}O_2$ Indicate That Isotopic Scrambling can be Eliminated by Pretreatment with $^{18}O_2$

- Reduce surface with H_2 to remove ^{16}O and re-oxidize with $^{18}O_2$

Table 3.4-5

CRITICALITY OF EQUIPMENT TO DESIGN ENVIRONMENT

SUBSYSTEM: Gas Regeneration ITEM	THERMAL VACUUM	THERMAL CYCLE	SINE VIBRATION	RANDOM VIBRATION	ACOUSTIC NOISE	PYROSHOCK	ACCELERATION	HUMIDITY	PRESSURE	LEAKAGE	CHEMICAL CORROSION	SHOCK VIBRATION	FLOW	HIGH VOLTAGE	EMP
Blower						o			o	o			o		
Regenerative Heat Exchanger		o	o	o	o	o	o		o	o		o	o		
Catalyst Container									o	o					
Catalyst Charge		o	o	o	o	o	o		o			o	o		
Catalyst Heater		o	o				o					o			
Filter		o	o	o	o	o	o		o			o	o		

Table 3.4-6

GAS REGENERATION COMPONENT RISK ASSESSMENT

SUBSYSTEM: Gas Regeneration

NATURE OF DEVELOPMENT		SUPPORTING ANALYSIS/DATA		FUNCTIONAL CRITICALITY		TOTAL
ITEM	VALUE		VALUE		VALUE	
CATEGORY		CATEGORY		CATEGORY		
ITEM BLOWER						
CATEGORY 5	1	4	1	1	3	3
ITEM REGENERATIVE HEAT EXCHANGER						
CATEGORY 4	2	4	1	2	2	4
ITEM CATALYST CONTAINER						
CATEGORY 4	2	4	1	1	3	6
ITEM CATALYST CHARGE						
CATEGORY 4	2	4	1	1	3	6
ITEM CATALYST HEATER						
CATEGORY 4	2	4	1	2	2	4
ITEM FILTER						
CATEGORY 4	2	4	1	2	2	4

Table 3.4-7

CATALYST DESIGN VERIFICATION TESTS

ISSUES

- Scaling to 50 Hz Operation

  Required catalyst surface area

- Isotopic Scrambling

  Is surface replacement with ^{18}O sufficient

DEMONSTRATION OF 10^7 SHOT OPERATION AT 50 Hz

- Use Markem CO_2 Laser with Catalyst Loop
- Monitor O_2 Concentration and Laser Power
- Repeat with Isotopically Selected $C^{18}O_2$

A number of small copper steering mirrors are used to transport the beams across the small NRC breadboard. The LO beam leaves the table, while the IO beam is taken to the input coupling hole of the PO through a beamsplitter, which samples the backscattered wave from the PO oscillator. This last beamsplitter generates the sample needed by the PO lock detector.

The heart of the system is the power oscillator resonator. This is a positive branch unstable resonator, with the large mirror (primary) replaced by a Littrow diffraction grating to provide rotational line selection. Outcoupling is from a diagonal scraper mirror located just inside of the secondary. The magnification of the resonator is 1.7. Wave optics calculations show that the actual outcoupling for the resonator is about 40 percent.

This resonator is not confocal, since to build a confocal resonator would have required a large, expensive, and perhaps even unobtainable curved diffraction grating. The use of a flat grating results in a mode that is slightly diverging at the output. The divergence angle is $\approx$2.4 mrad. Note that this divergence does not represent a loss of beam quality. There is no loss of beam focusability, but there is a focal shift due to the divergence.

The injection laser is introduced thorugh a small hole drilled in the secondary mirror. The size of this hole is selected as a compromise between incoupling efficiency and the effect of the hole on the unstable resonator mode. The critical parameter is the radius of the resonator Fresnel core, which is given by a = sqrt($\lambda \ell$). If the injection hole radius is small compared with a, then the mode is little affected by the presence of the hole. On the other hand, the effective incoupling efficiency decreases roughly as the area of the hole. For the PO resonator, a = 6 mm, while we have chosen an incoupling hole radius of 1.5 mm.

The proper PO resonance condition is identified by sensing the standing wave power in the resonator due to the IO between pulses. When the PO mode has the same frequency as the injection signal, then the standing wave power inside the Fresnel core builds to a maximum. This process is exactly analogous to a conventional Fabry-Perot except that part of the feedback process that leads to standing wave buildup is due to diffraction rather than simple reflection. Nonetheless, the same phenomenology applies, and the internal standing wave power is at a maximum when the input signal and cavity are resonant. The existence of this resonance is detected by looking at the power propagating back through the injection port, which is simply a sample of the on-axis standing wave power.

The servo system, which must locate the maximum, or zero derivative point, requires a dither. Rather than dithering the cavity length, we exploit the fact that the injection signal is already frequency modulated due to the IO dither. The comparison of input frequency and cavity length is made by dithering the frequency rather than the length.

Finally, after the pulsed beam leaves the PO resonator, it is demagnified by an inverted Cassegrian-type telescope to a nominal diameter of 18 mm before leaving the laser system. The telescope exploits the annular nature of the beam from the PO to perform this function without any shadowing loss due to the secondary mirror. The mirror spacing is increased above the confocal value to compensate for the diverging output mode from the PO resonator.

The optical system for the SCALE transmitter is identical in size and spatial configuration with the WINDVAN configuration. The WINDVAN design required a degree of hardening over what might be required of a laboratory device due to the extremes of environment to which it is exposed when mounted in a trailer. Rough terrain and temperature extremes, comparable

in range with the SCALE mission, required careful attention during the design phase. The primary concern in achieving a successful upgrade of WINDVAN to the SCALE mission is the need to maintain the physical alignment of the system during launch and on station maneuvers. Adjustments to the WINDVAN system by the operators in the field are required to keep the optical system in proper alignment. These adjustments are simple and are accomplished manually by manipulating mirror mount micrometer actuators in conjunction with targets inserted into the beam path. Performing such procedures remotely becomes an exceedingly difficult task requiring a large number of actuators and detectors in a control system of formidible complexity. Since remote operation is the only mode under consideration for the SCALE mission, a great deal of attention has been given to this problem during this study. The objective is to characterize the problem quantitatively by examining the thermal and mechanical design environment on a space hardened configuration composed of the minimum number of subunits which could be aligned with respect to one another and to assign values to the allowable errors for each of the components in the optical system.

3.5.2 Optical System

The schematic layout of the transmitter system was shown previously in Figure 2-1. The physical layout is shown in Figure 3.5-1. The plan view shows the size and location of each of the elements of the system. A structural concept which addresses the design issues presented above is shown in Figure 3.5-2. Separately mounting the laser from the optical bench, with the latter containing the transmitter cavity optics and the rest of the components, serves the dual purpose of isolating the relatively massive laser head from the rest of the optics during the potentially destructive launch phase and preventing vibrations originating in the laser from affecting the optics during transmitter operation. Statically determinate truss systems provide a strain-free mounting structure for the bench and the laser/modulator. An additional feature shown in the figure is an acoustic barrier that surrounds the optical bench to attenuate the

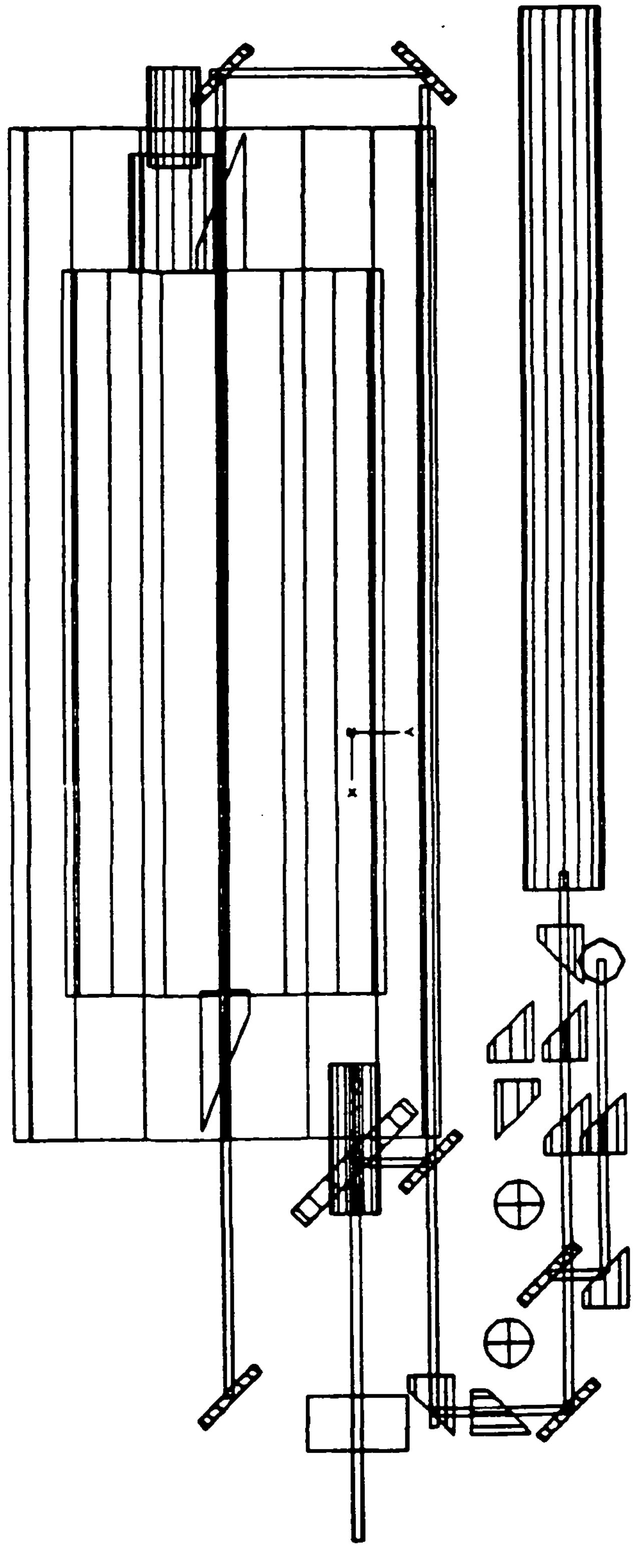


Figure 3.5-1. WINDVAN Optical Layout

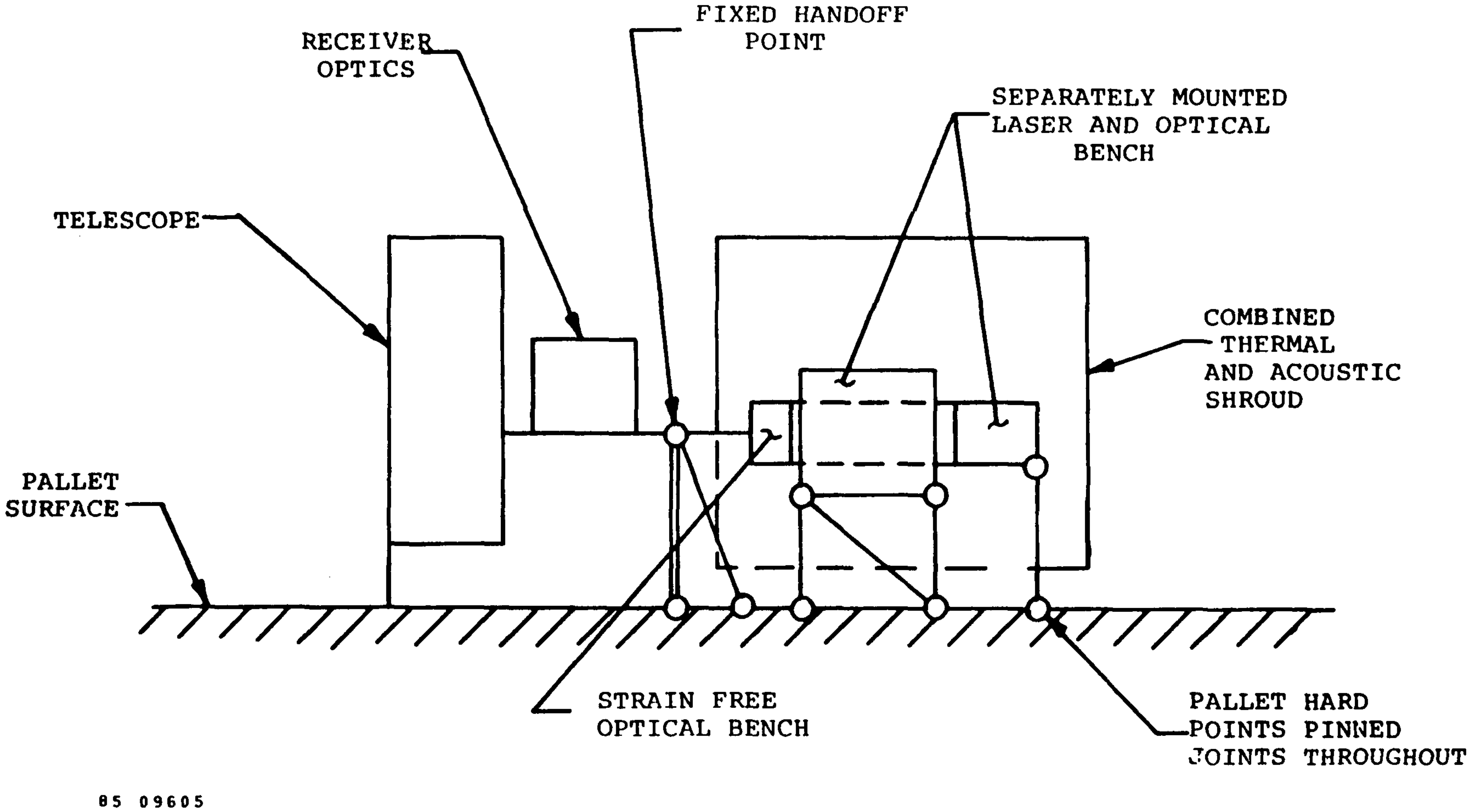


Figure 3.5-2. Structural Concept

large amplitude pressure waves present in the cargo bay during the launch. The structural relationship between the transmitter and the rest of the major SCALE components also is shown. The advantage of interconnecting these components at a single fixed hard point is that the thermal expansion of the components can take place in a controlled way.

The physical manifestation of this approach is shown in Figure 3.5-3. The laser, the optical bench, and the acoustic shell are shown rigidly attached to the ESA pallet. The intended function can be accomplished equally well by reinforcing the shell structure until it is comparable in stiffness to the pallet structure and then mounting the laser and bench directly to the shell. Details of the expected performance of each of these components are given below.

The laser mounting scheme shown in Figure 3.5-4 illustrates the load path from the laser/modulator to the ESA pallet hardpoints via a system of ball and socket mounted rigid rods, with the shells of the laser and modulator acting as load carrying structure. The truss system fixes one end of the laser on the pallet, with the other end unrestrained in the axial direction. Figure 3.5-5 shows a similar arrangement for the optical bench. The table is made of low coefficient of thermal expansion material as is the space frame holding the cavity optics. Three options for the optical table design include: (1) a custom-fit unit with carbon fiber L-brackets molded into the table surface; (2) a flat carbon fiber table with simple brackets; and (3) a semi-kinematic space frame or a regular optical table with fully kinematically mounted spaceframe for resonator optics, i.e., the WINDVAN approach.

The details of the acoustic protection system are shown in Figure 3.5-6. An external thermal blanket provides thermal insulation and some degree of sound attenuation. An aluminum skin on the outside of a monocoque shell structure protects against the cargo bay noise and an open cell lead foam, such as that used to isolate passengers from the engine noise on commercial aircraft, prevents the build-up of disturbances within the shell.

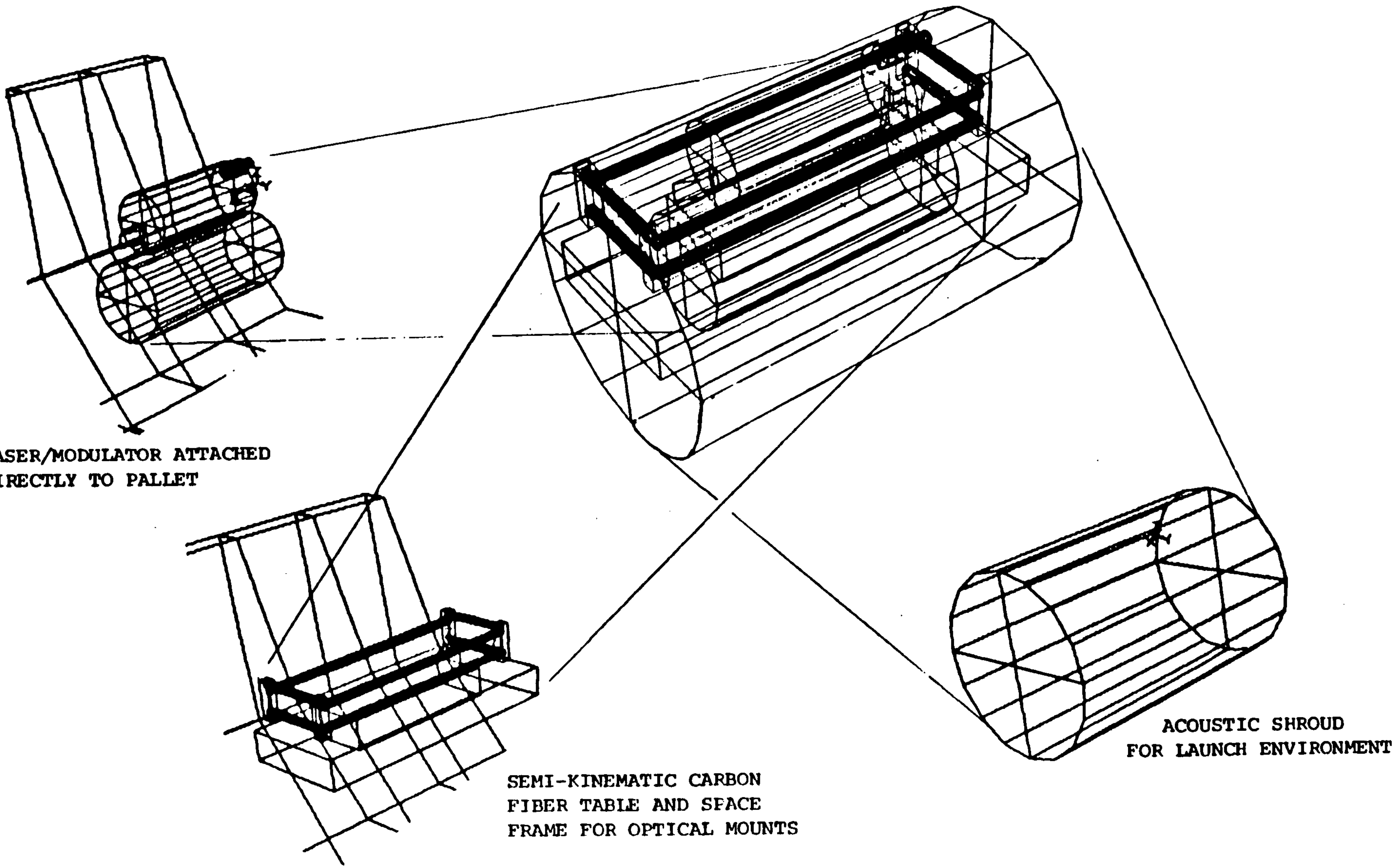


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Figure 3.5-3. Structural Configuration

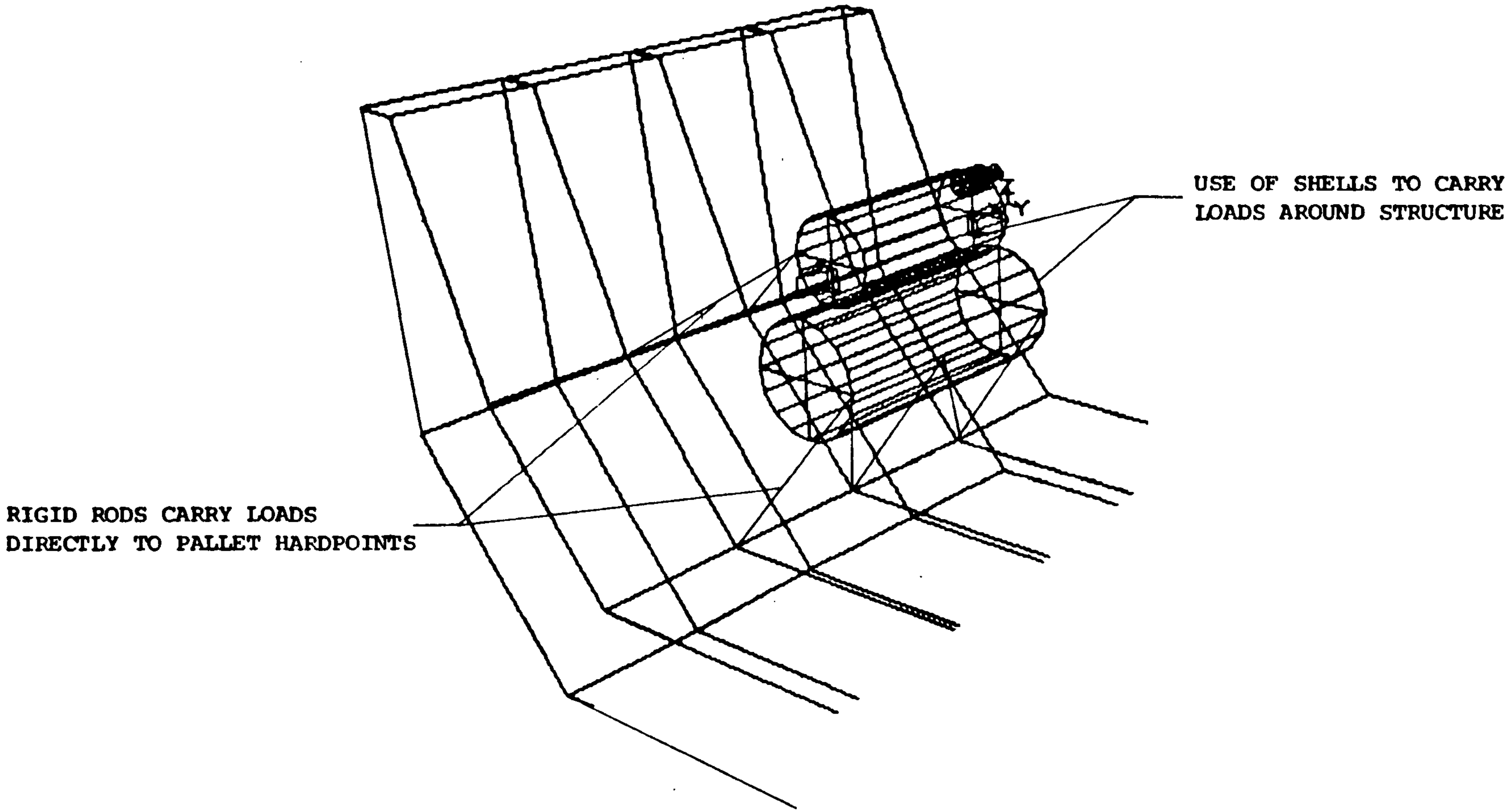

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Figure 3.5-4. Laser/Modulator Mounting

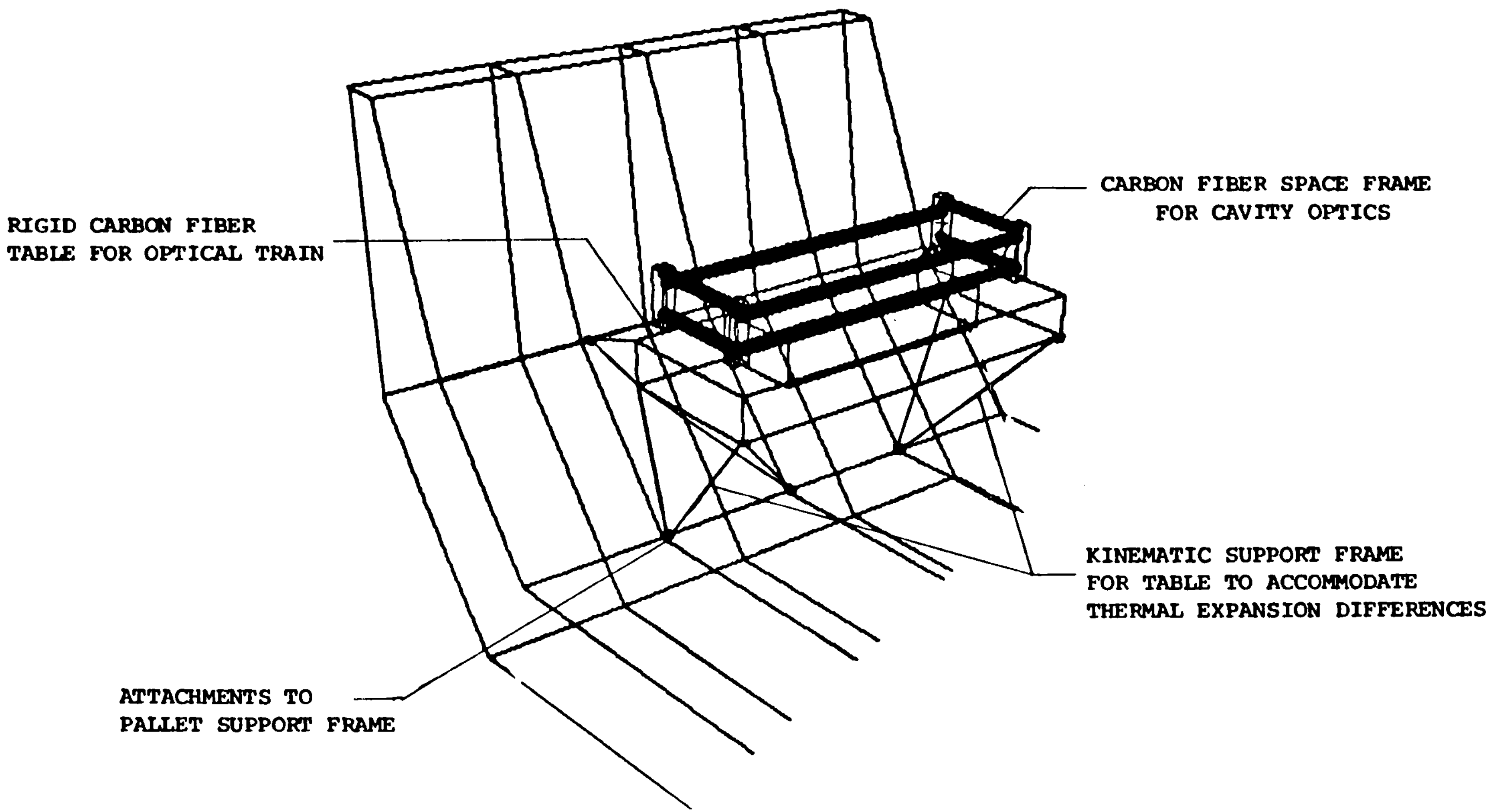

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Figure 3.5-5. Optical Table and Space Frame

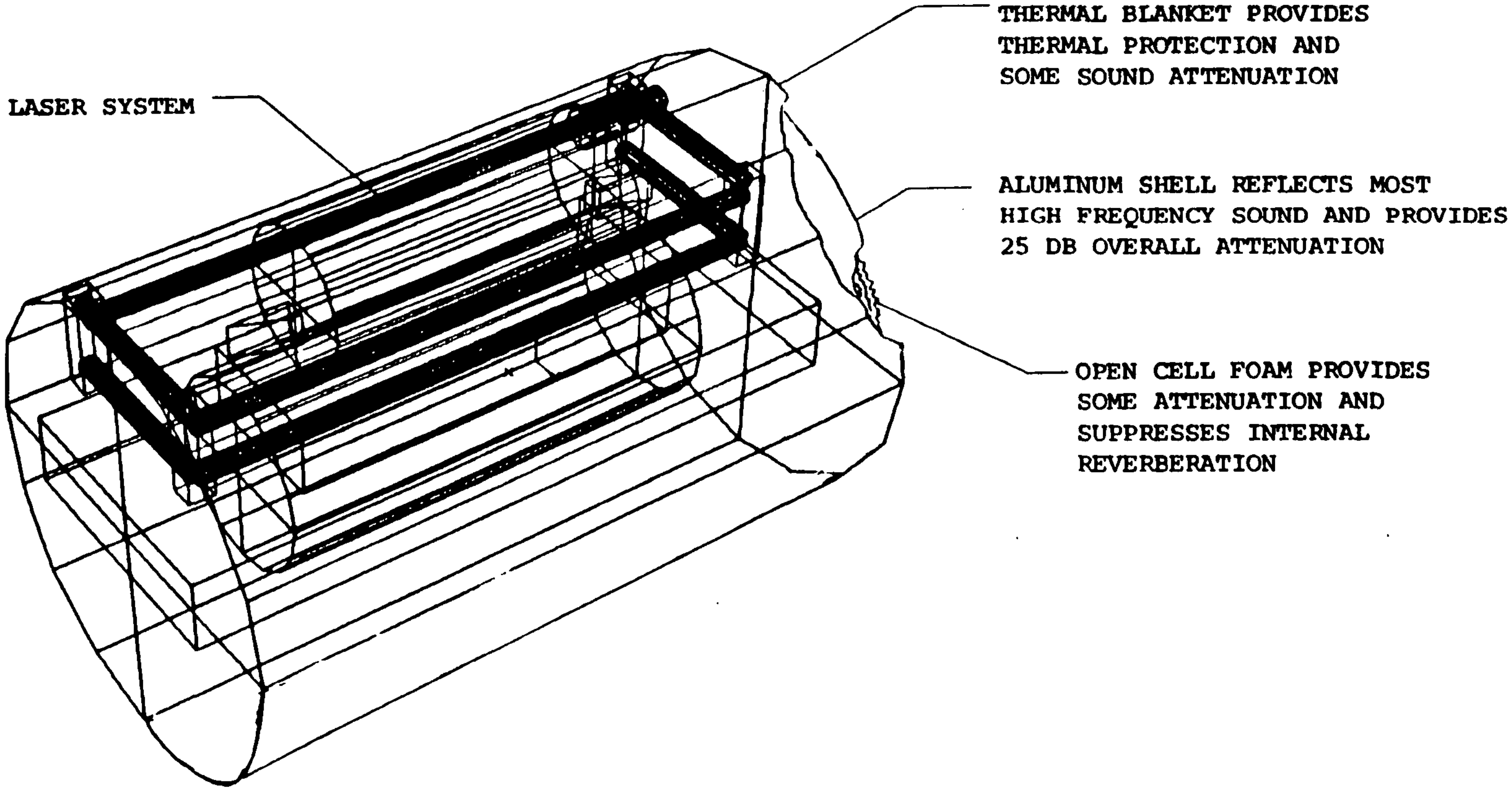

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Figure 3.5-6. Acoustic Protection System

The performance of a simple acoustic shield is shown in Figure 3.5-7. In the region below 20 Hz, the sound wave buffets the structure, with the effects being felt increasingly as the first resonance, the out-of-round flexing of the cylinder, is approached. In the region above the first resonance, the inertia of the wall attenuates with a f^{-2} dependence. At very high frequencies, transverse modes within the walls decrease the shell's performance.

Figure 3.5-8 shows the magnitude of the acoustic problem in the shuttle bay during launch. The upper curve in that figure gives the spectrum of the acoustic noise in the shuttle bay. The peak intensity occurs at around 400 Hz and has a magnitude of 145 dB. This level can be expected to misalign components. With the addition of the simplest shroud, the 1/8 inch shell, the peak amplitudes (see lower curve) drop by 20 dB to a level which the mounts can be expected to tolerate.

To provide an additional degree of confidence that a largely passive alignment approach would be attainable, a test was performed on a commercially available flexure mount. Figure 3.5-9 shows the test setup and the results. A laser ranger and reflecting optic sensitive to 0.1 arc were used to measure the relaxation of the mount, which was subjected to intense vibration at its set-screw adjustments from an engraving tool. The results show a decrease in drift with vibration time, suggesting that this method, if used to stabilize the optical alignment before launch, can be expected to hold the alignment within the error budget through launch.

Defining an alignment strategy that would insure the success of the mission while minimizing the number of active elements was also addressed as part of the optics task. The first step is to divide the lidar system into physically related subunits. This is illustrated in Figure 3.5-10. The next goal is to provide adequate passive stability within subunits; active alignment is then provided between subunits, as needed. The

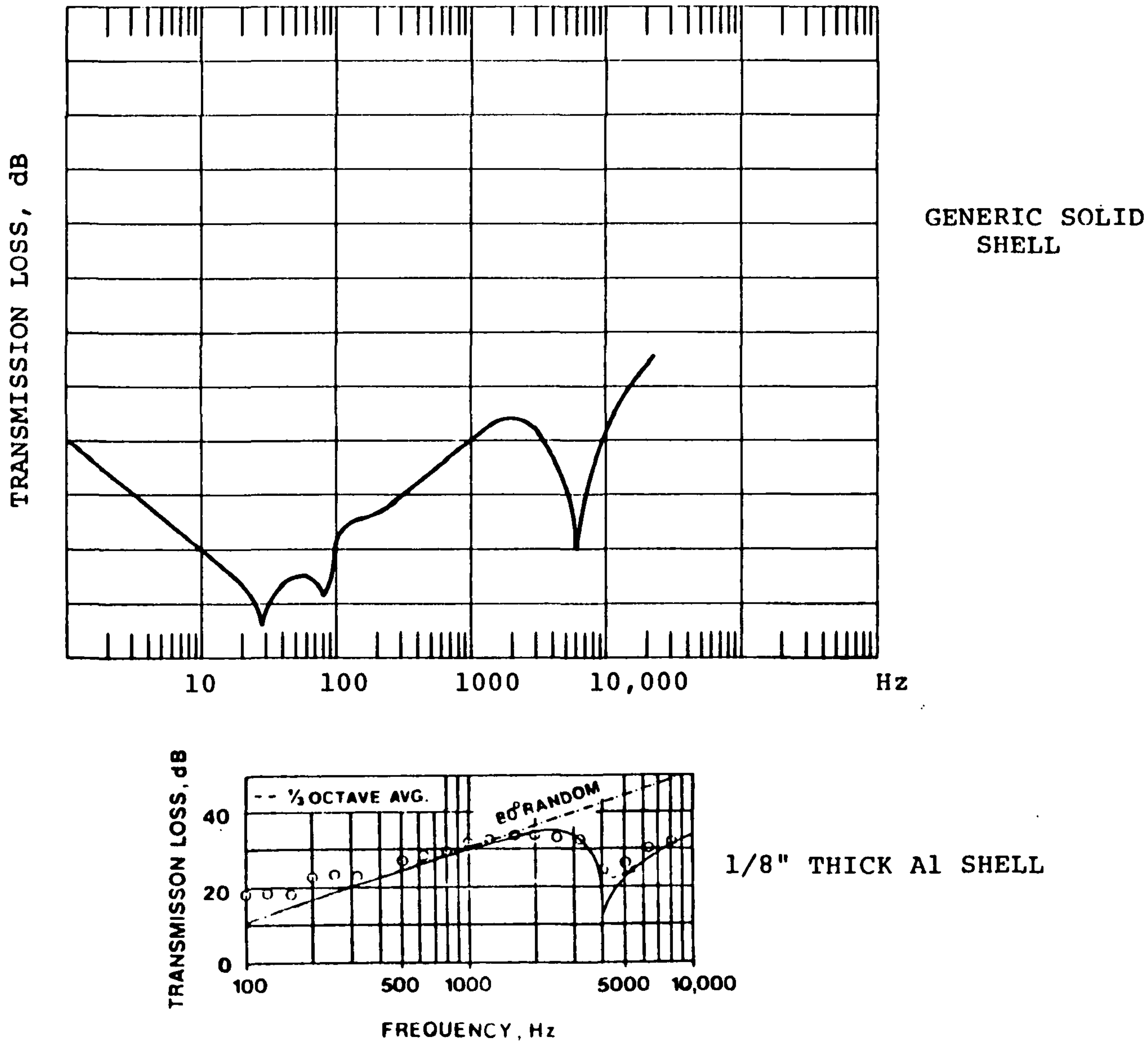


Figure 3.5-7. Acoustic Performance of Simple Shield

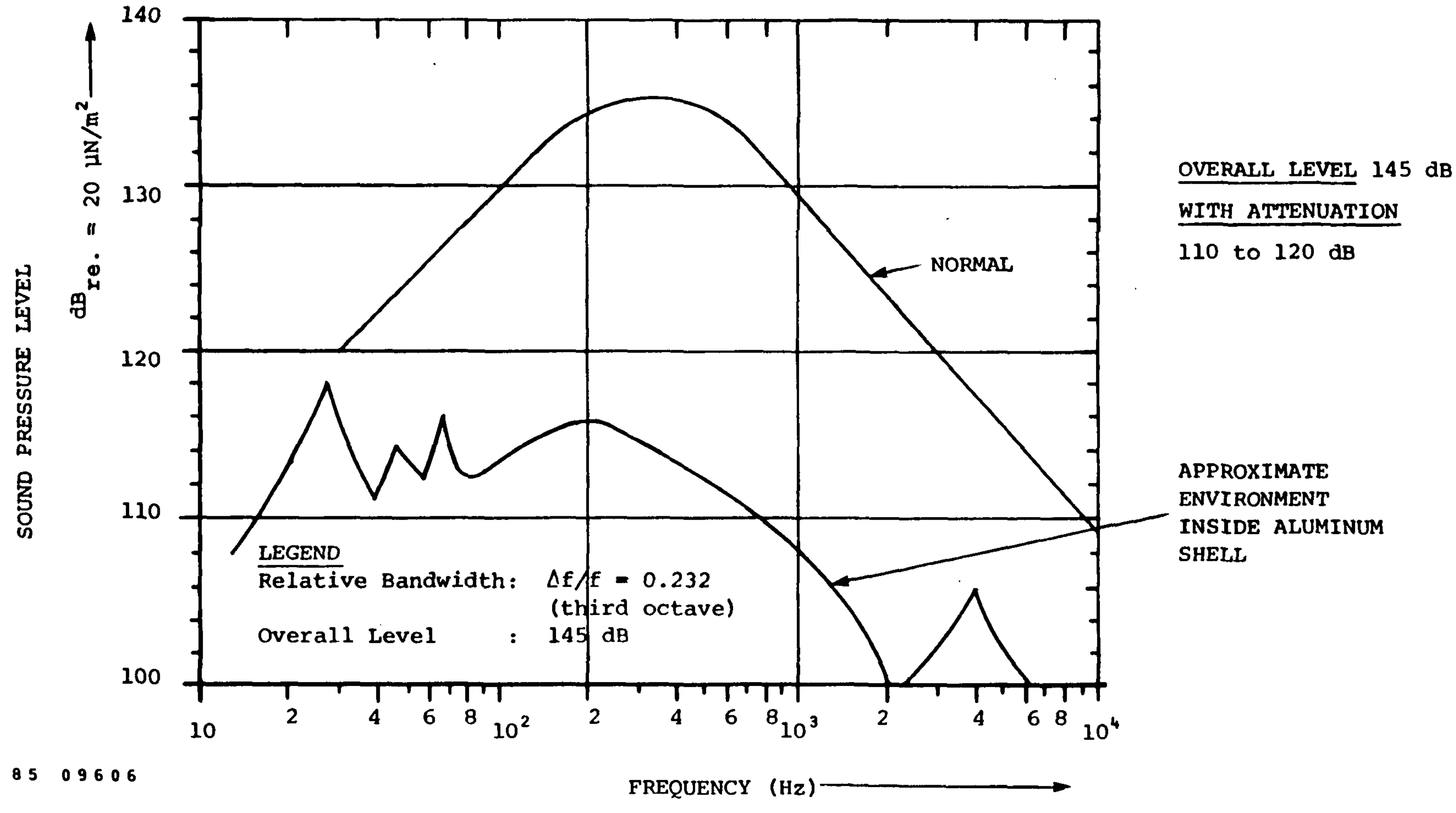
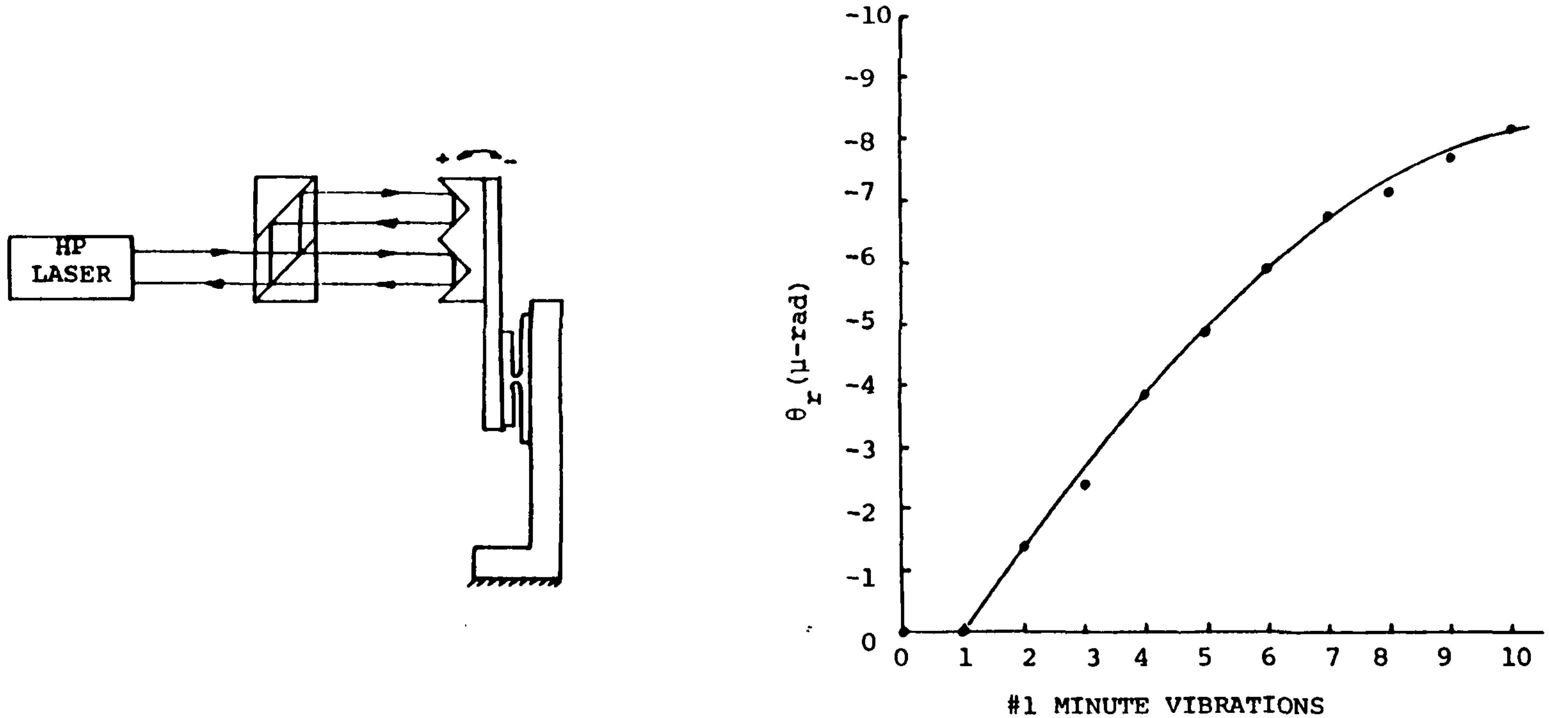


Figure 3.5-8. Acoustic Environment Within the Shuttle Paylcad Bay



- After initial vibrational relaxation, the mirror mount was stable when vibrated for 3 minutes.
- Probably use static mirror mounts in flight system.

Figure 3.5-9. Preliminary Vibration Test of Mirror Mount

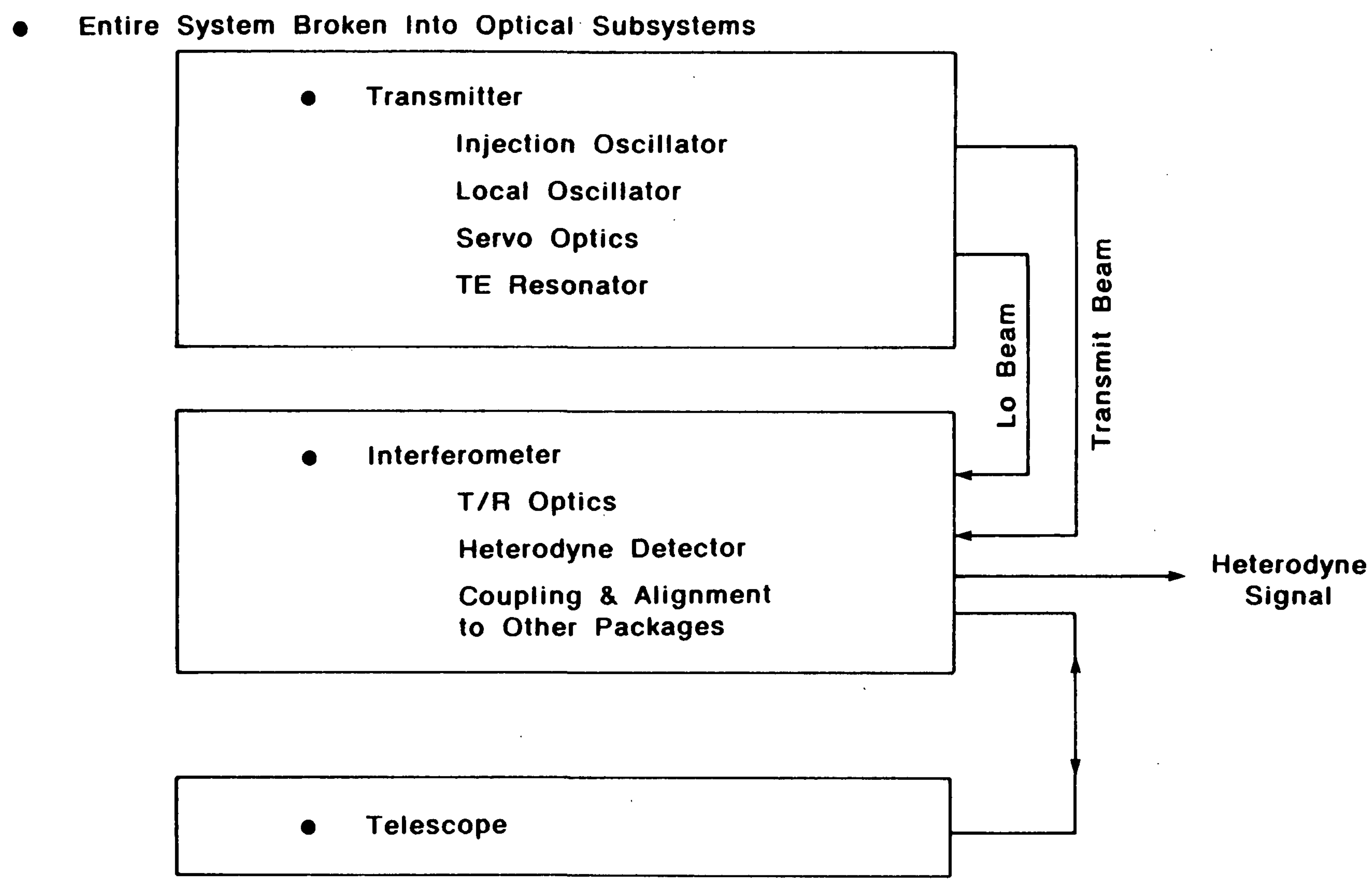


Figure 3.5-10. Optical Alignment Considerations

physical embodiment of this objective is discussed further below. The critical alignment point is the transmitter TE resonator, which has stringent requirements and large physical size.

Figure 3.5-11 depicts the division of alignment functions. The transmitter bench and its components deliver high quality beams to the interferometer bench. The interferometer bench provides the alignment function between the transmitter beams and the telescope input/output beams. The error budget for the transmitter alignment is given in Table 3.5-1.

3.5.3 Active Alignment Approach and Procedure

The actively aligned elements of the transmitter use the injection and local oscillator beams as sources. Quadrant pyrolytic detectors placed at critical nodes require AM modulation of the cw lasers. Beams are sampled by permanent beam splitters. A small number of alignable optics will be required. Mounts will be actuated by magnetic, thermal, hydraulic, mechanical, or piezoelectric methods. During initial alignment, a large number of misalignments must be dealt with. This will be time consuming and will require a multiparameter search procedure before the lidar can be actuated. This process uses little power. On-station alignment will be continuous, closed loop, and low bandwidth. Finally, the optical alignment sensitivity can be reduced through optical design measures, such as overfilling the servo detectors to reduce overlap sensitivity. The transmitter active alignment components are listed in Table 3.5-2.

3.5.3 Criticalities

Criticality of the optical eqiupment to the design environment is given in Table 3.5-3.

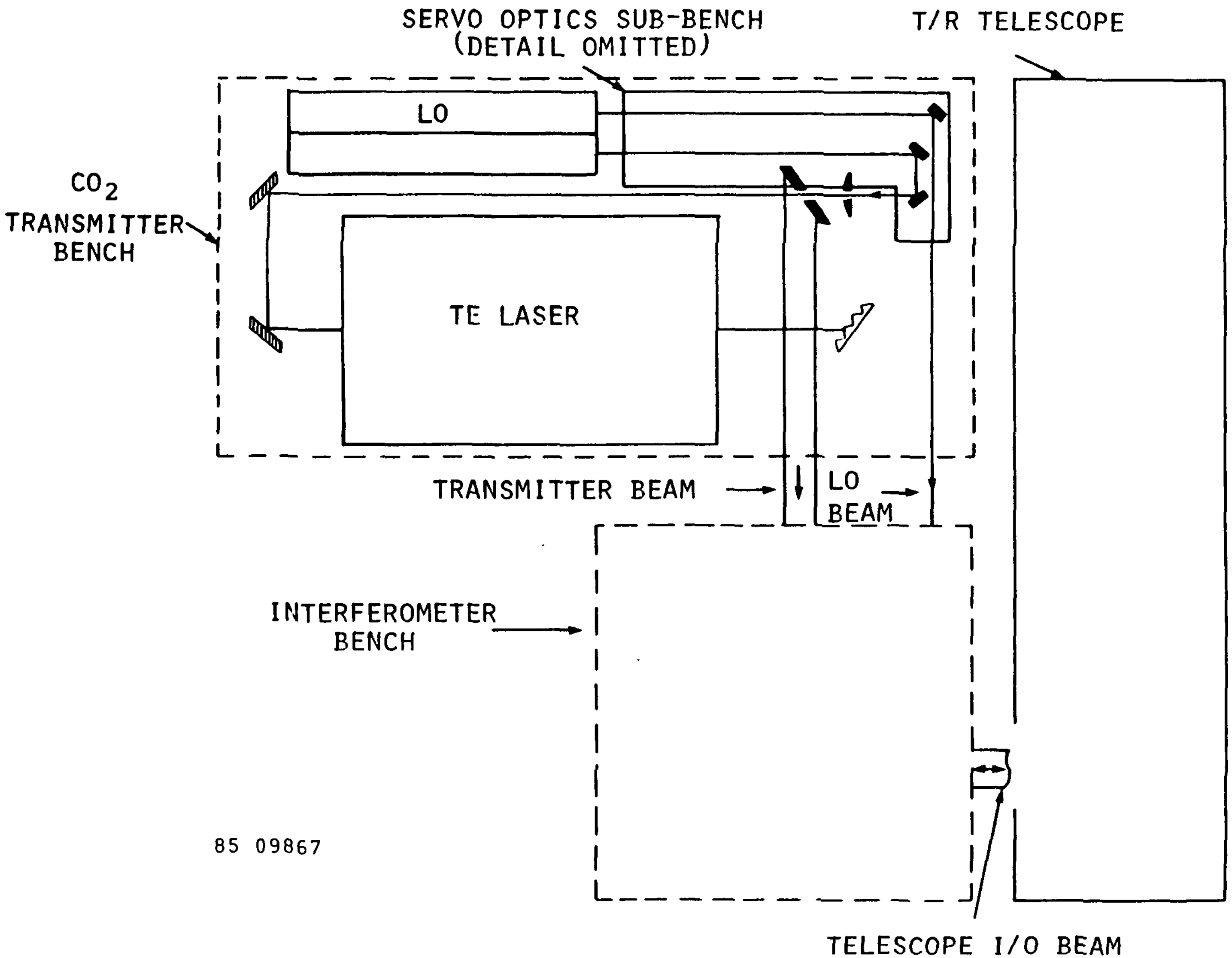


Figure 3.5-11. Division of Alignment Function

Table 3.5-1

PRELIMINARY TRANSMITTER ALIGNMENT BUDGET

Subunit	Solid-Body Motion of Subunit With Respect to Transmitter Bench	Single-Optic Motion With Respect To Subunit
Injection Oscillator	0.3 mrad	$\leqslant$ 1 mrad
Local Oscillator	0.3 mrad	$\leqslant$ 1 mrad
Servo Sub-Bench	0.3 mrad	100 μrad
TE Resonator Optics	NA	50 μrad
TE Laser Head	1 mm transverse	10 mrad

Table 3.5-2

TRANSMITTER ACTIVE ALIGNMENT HARDWARE REQUIREMENTS

IO, LO	None
Servo Sub-Bench	4 quadrant detectors 12 actuators
TE Resonator	2 quadrant detectors 4 actuators

Table 3.5-3

CRITICALITY OF EQUIPMENT TO DESIGN ENVIRONMENT

SUBSYSTEM: Optical/Structural ITEM	THERMAL VACUUM	THERMAL CYCLE	SINE VIBRATION	RANDOM VIBRATION	ACOUSTIC NOISE	PYROSHOCK	ACCELERATION	HUMIDITY	PRESSURE	LEAKAGE	CHEMICAL CORROSION	SHOCK VIBRATION	FLOW	HIGH VOLTAGE	EMP
Optical Table		o	o	o	o	o	o					o			
Cavity Space Frame		o	o	o	o	o	o					o			
Infrared Detectors														o	o
Oscillators		o	o			o						o			
Servo Sub-Bench			o	o	o										
TE Laser Resonator			o	o								o		o	
Acoustic Shell	o		o	o	o		o								o

3.5.4 Risk Assessment

The component risk assessment is presented in Table 3.5-4. It is anticipated that a design verification test will be required to substantiate the maximally passive design goal.

3.6 CONTROL AND DATA SUBSYSTEMS

3.6.1 WINDVAN Control Configuration

The WINDVAN transmitter is controlled by a standard commercial-grade microcomputer (DEC LSI-11/23). This processor performs automated system startup and shutdown housekeeping functions. During normal operation, a wide variety of error detection and recovery functions are active. All normal operator functions are performed via a touch-screen CRT terminal, using a multimenu "soft pushbutton" approach.

Other than the touch screen, the only other operator contact required for normal operation is turning on of circuit breakers, when starting from a cold condition, and alignment of optics using manual mount controls.

Storage of the operating program and system configuration information is on a small Winchester disk. Interface to the transmitter hardware is via a single parallel port interfaced to the microprocessor bus (Q-bus). Serial RS232 ports on the bus are used for the operator terminal, and for command input and status output to a master lidar processor.

3.6.2 SCALE Control Configuration, Requirements, and Criticality

The proposed SCALE configuration is much the same. A single modest local processor is adequate to handle all transmitter housekeeping and monitoring functions. As described in Section 3.5, autoalignment functions must be added to the set of control functions currently implemented in WINDVAN. Low bandwidth bidirectional communications, either to the ground

Table 3.5-4

OPTICAL/STRUCTURAL COMPONENT RISK ASSESSMENT

NATURE OF DEVELOPMENT		SUPPORTING ANALYSIS/DATA		FUNCTIONAL CRITICALITY		TOTAL
ITEM OPTICAL TABLE	VALUE		VALUE		VALUE	
CATEGORY 3	4	CATEGORY 3	2	CATEGORY 1	3	24
ITEM CAVITY SPACE FRAME						
CATEGORY 3	4	3	2	1	3	24
ITEM IR DETECTORS						
CATEGORY 4	2	4	1	1	3	6
ITEM OSCILLATORS						
CATEGORY 4	3	4	1	1	3	6
ITEM SERVO SUB-BENCH						
CATEGORY 4	2	4	1	1	3	6
ITEM TE RESONATOR OPTICS						
CATEGORY 4	2	4	1	1	3	6
ITEM						
CATEGORY						

or to a mission-specialist operating panel, will allow remote operation and status monitoring. Remote operation of prime power and coolant shutoffs is envisioned to be performed by the mission specialist. These requirements are summarized in Table 3.6-1.

Table 3.6-2 summarizes the criticality of data-related components in the standard format of this report. The control components are essential to successful transmitter operation and, hence, must be engineered for maximum reliability in the STS environment.

3.6.3 Risk Assessment

Table 3.6-3 summarizes the component level risk assessment in the format used throughout this report. The technology associated with the data and control functions is extremely well developed, but also critical to the mission. The overall risk associated with these elements of the transmitter design remains low because of the excellent engineering database available, both for the control requirements and for the technology necessary to implement those controls.

Table 3.6-1

CONTROL AND DATA REQUIREMENTS
FOR SPACE SHUTTLE LIDAR TRANSMITTER

- o Local Transmitter Controller ≈ 0.1 MIPS
  - Autoalignment
  - Laser system startup, sequencing, shutdown
  - Servo autolock and monitor
  - Fault detection and protection
- o Downlink Data Rate ≈ 2400 bps
  - Transmitter status
- o Uplink Data Rate ≈ 300 bps
  - Transmitter command
  - Parallel mission specialist command?

Table 3.6-2

CRITICALITY OF EQUIPMENT TO DESIGN ENVIRONMENTS

DESIGN ENVIRONMENTS

SUBSYSTEM:

ITEM	THERMAL VACUUM	THERMAL CYCLE	SINE VIBRATION	RANDOM VIBRATION	ACOUSTIC NOISE	PYROSHOCK	ACCELERATION	HUMIDITY	PRESSURE	LEAKAGE	CHEMICAL CORROSION	SHOCK VIBRATION	FLOW	HIGH VOLTAGE	EMP
Telemetry Interface	o	o	o	o		o	o								o
Supervisory Computer	o	o	o	o		o	o								o
Sensor and Control Electronics	o	o	o	o		o	o								o

Table 3.6-3

DATA AND CONTROL COMPONENT RISK ASSESSMENT

NATURE OF DEVELOPMENT		SUPPORTING ANALYSIS/DATA		FUNCTIONAL CRITICALITY		TOTAL
ITEM TELEMETRY INTERRACES	VALUE		VALUE		VALUE	
CATEGORY 4	2	CATEGORY 4	1	CATEGORY 1	3	6
ITEM SUPERVISORY COMPUTER						
CATEGORY 4	2	4	1	1	3	6
ITEM SENSOR AND CONTROL ELECTRONICS						
CATEGORY 4	2	4	1	1	3	6
ITEM						
CATEGORY						
ITEM						
CATEGORY						
ITEM						
CATEGORY						
ITEM						
CATEGORY						

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Section 4

TRANSMITTER DEVELOPMENT PLAN

4.1 OVERVIEW

We divide development into Conceptual Design (Phase A), Preliminary Design (Phase B), and Detailed Design and Development Phases (Phase C/D). Figure 4-1 shows the logical relationship of the activities within these various phases.

No major technology development is required for the transmitter concept presented in this report, but the need for additional testing of certain critical components is anticipated. We believe that these tests are most appropriate during Phase B, or perhaps even earlier. These tests will completely resolve all remaining uncertainty concerning the capability of WINDVAN technology to meet SCALE requirements. After these tests have been completed, development of the SCALE transmitter can proceed along a well defined path using established space hardware methodology.

Details of the recommended development activities are described in Section 4.2. Because of the importance of the qualification testing to determination of both program costs and risk, the test plan is described separately in Section 4.3. In Section 4.4 we develop a cost estimate of the complete development cost of a flightworthy transmitter, through delivery to KSC for shuttle integration. Section 4.5 is a summary of STI's conclusions and recommendations concerning development of a SCALE transmitter based on WINDVAN technology.

4.2 DETAILED DEVELOPMENT PLAN

Figure 4-2 shows the schedule for the suggested program. The goals of each phase are described below. Total elapsed time for development of the transmitter is estimated to be 56 months, from start through delivery

C.2

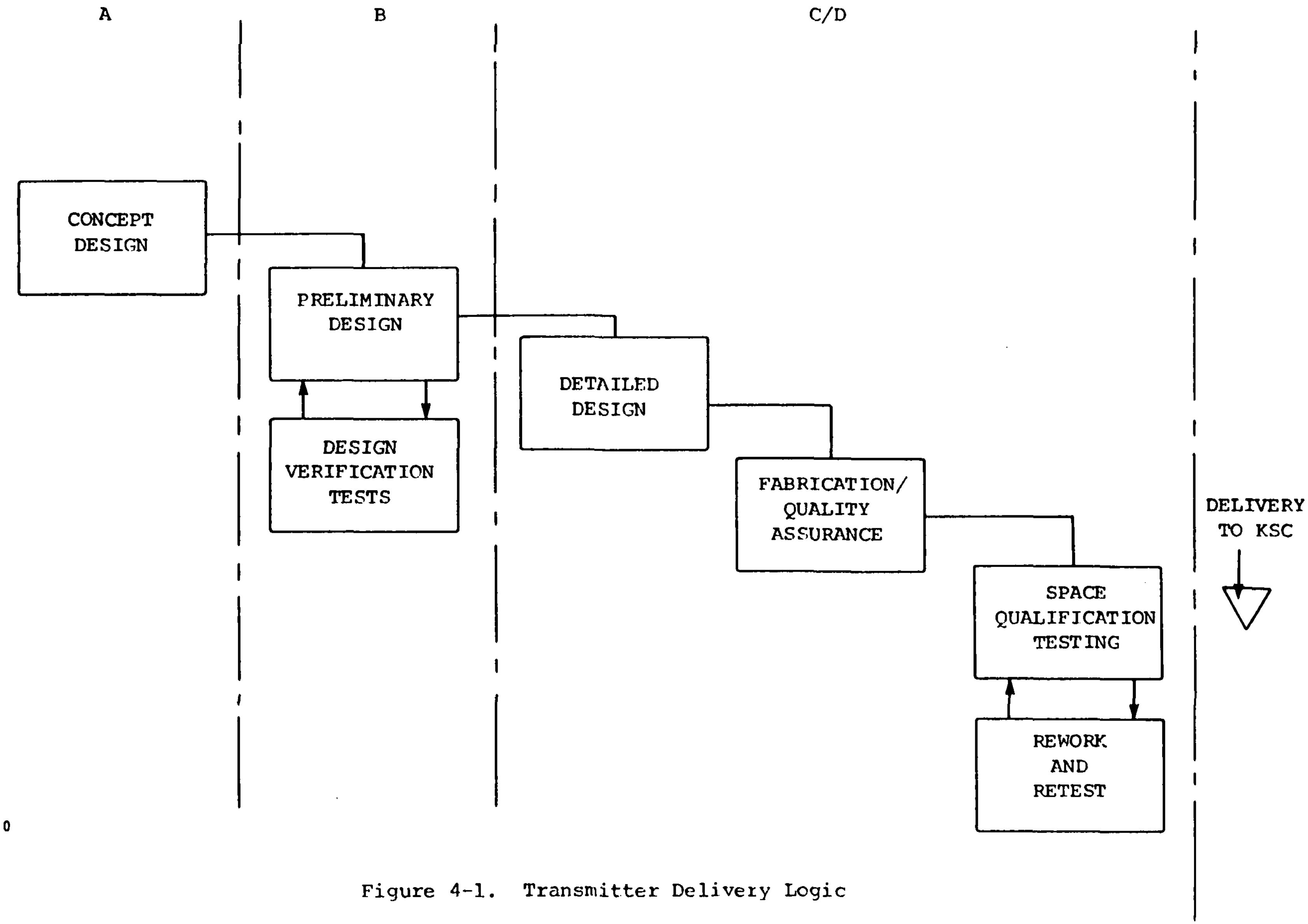

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Figure 4-1. Transmitter Delivery Logic

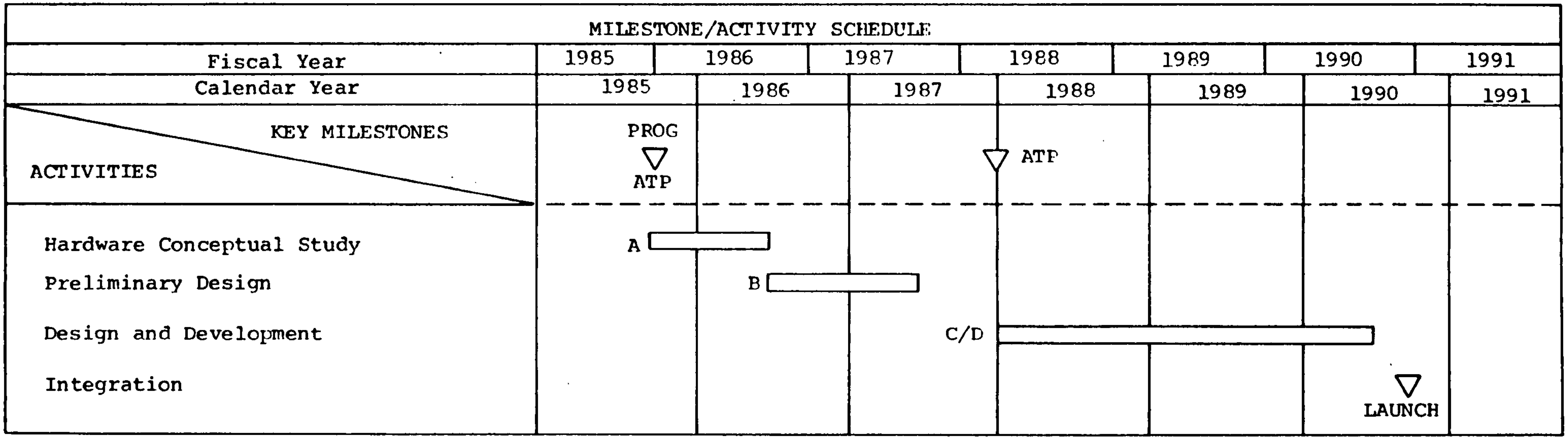

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Figure 4-2. Program Schedule

to KSC. The schedule shown includes a slightly longer total elapsed time because of interfaces with the NASA decision making process.

Phase A

The hardware conceptual design phase leads to a final definition of the transmitter approach. Technology selection and rough configurations for all transmitter subsystems will result from this study. Any transmitter components requiring further development or testing and any areas of special risk will be identified during this phase. A complete description of the projected transmitter performance also will be developed.

Phase B

Phase B will result in complete definition of the transmitter configuration. System layouts, preliminary interface definition documents, and identification of component level requirements are the primary outputs of Phase B.

Component performance requirements will be compared with the state of the art. In those areas where there is insufficient design data to make this comparison, or if there is a concern as to component adequacy, special tests will be designed to validate the required performance levels. Table 4-1 lists the series of such tests that we currently envision to be required.

Using the existing technology database, augmented by the results of the proposed design verification tests, Phase B should result in elimination of all uncertainties concerning the technical feasibility of the SCALE transmitter approach.

Table 4-1

TRANSMITTER DESIGN VERIFICATION TESTS

Component	Issue	Test Description
Modulator	Solid-state Switch Performance	Breadboard Modulator Dummy Load
Optical Bench Structural Supports	Passive Alignment	TBD
Gas Utilization**	Catalyst Performance Operating Temperature	Breadboard Regeneration Flow Loop
Preionizer	Corona Bar Life	Breadboard pulsed CO_2 laser*

* e.g., STI 20 W CDL laser

** Not required, if gas rejection acceptable; not currently costed

Phase C\D

Phase C\D begins with detailed engineering design of the complete transmitter subsystem, including STS and SCALE interfaces, support hardware, and any special tooling required. After design completion and review, procurement and fabrication begins, leading to full transmitter system assembly and functional checkout. To ensure appropriate costing, the necessary design documentation and quality assurance appropriate to a flight-qualified device have been explicitly identified.

Qualification testing is described in detail in Section 4.3. The final Phase C\D task consists of rework and retest to correct deficiencies uncovered during qualification testing.

4.3 QUALIFICATION TEST PLAN

We envision that six distinct types of testing will be required to qualify the SCALE transmitter system. These are (1) mechanical mode analysis, (2) vacuum-thermal exposure, (3) EMI generation, (4) static mechanical loading, (5) acoustic loading, and (6) life testing. These tests will be applied, as appropriate, to individual transmitter subsystems and then to the full transmitter system as a unit. The full system test series is proposed to occur twice. The second full system test will validate the success of any rework required to correct deficiencies. Table 4-2 shows in matrix form which tests will be applied to which transmitter subsystems.

4.4 ESTIMATED DEVELOPMENT COST

We have estimated the cost of development of a SCALE transmitter from conceptual design through delivery to KSC in flight-ready condition. These costs are summarized in Table 4-3. The basis for these estimates follows.

TEST / COMPONENT	Modal Analysis	Vacuum Thermal	Electromagnetic Interference	Static Loading	Acoustic Vibration	Life
Laser Head	O			O	O	O
Modulator	O		O	O	O	O
Optical Bench/ Optics	O			O	O	O
Data Handling & Control Electronics			O			O
Assembly	O	O	O	O	O	O

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Table 4-2. Transmitter Space Qualification Tests

Table 4-3

SUMMARY OF PROJECTED DEVELOPMENT PROGRAM COST

Activity		Cost, $K
PHASE A		250
PHASE B		
Preliminary Design	500	
Design Verification Tests	1150	
PHASE C/D		
Detailed Design	900	
Documentation/Test Plan	1300	
Fab/Assembly/Functional Test	3600	
Quality Assurance	500	
Qualification Testing	2150	
Rework/Retest	1500	
Program Management	995	
		10,945
DEVELOPMENT TOTAL		12,845

Phase A costs are projected from the effort involved in the conceptualization of the WINDVAN design and from the effort invested in this study.

Phase B costs are dominated by the DVT effort, which has been estimated by comparison with similar STI technology programs. The remaining design cost is based on the WINDVAN experience, scaled by a complexity factor to account for space-related design issues.

In Phase C/D, a number of cost rationals are used. Detailed design is based on the WINDVAN experience, with an overall factor applied for the more complex space-qualified design. In addition, a documentation cost for STS interface specification, test planning, installation and operation manuals, and safety and qualification assurance has been included. Fabrication and checkout costs are based on WINDVAN experience. Quality assurance costs for compliance with space requirements have been assigned at the level of ≈15% of fabrication costs.

Testing has been costed using the test plan described in the previous section. Pricing on a per-test basis is assigned using values obtained from an active aerospace testing vendor (generous assistance of Ball Aerospace Division is gratefully acknowledged).

Rework has been assigned a cost equal to 25% of initial fabrication. Retesting has been costed using the same per-test costs as previously described.

4.5 CONCLUSIONS AND RECOMMENDATIONS

We conclude that a SCALE transmitter using the basic WINDVAN design approach is feasible. Development of new technology is not required. Appreciable engineering redesign will be required for repackaging the WINDVAN design for shuttle compatability. A more compact pulsed power layout has been proposed, and many design changes will be required for

vacuum compatability and for improved launch/landing survivability. In addition, some degree of remote optical alignment capability may be required.

The transmitter concept developed in this study provides performance equal in all respects to the NOAA/STI WINDVAN transmitter. The predicted prime power consumption, size, and weight of the transmitter are given in Table 4-4. Since full 50 Hz operation results in power consumption that exceeds MSFC goals, the power required for 25 Hz operation is also given in the table.

The only significant change of approach identified is the replacement of thyratron pulsed power switches with solid-state elements. The basic switching devices (RBDTs) proposed are well proven, but their use in a discharge pumped laser is not. As a result, tests to optimize matching of a solid-state switch to the laser load are recommended as part of the Phase B Design Verification Tests. Life testing of the solid-state devices under realistic laser loads also is recommended.

In summary, we can find no major technological barrier to successful development of a SCALE transmitter using WINDVAN design principles. The few remaining technology issues can be resolved by a set of relatively small Design Verification Tests, which can be completed very early in a SCALE development program. Since the proposed DVTs are not extremely design specific, it may be desirable to accelerate some or all of them. The engineering task which remains is substantial, but tractable. It should begin as early as possible to allow maximum reduction of risk in the resulting design.

During this study, the authors have come to believe that a SCALE mission in the early 1990s is an attainable goal. This optimism is a result of the study and was not a starting point. However, this goal can be met only with a strongly focused, concerted development program that begins as soon as possible.

Table 4-4

SUMMARY OF SCALE TRANSMITTER POWER, WEIGHT, AND VOLUME REQUIREMENTS

Subsystem	**Power (W) @50Hz**	**Power (W) @25Hz**	**Weight (Kg)**	**Volume (cu m)**
Laser (Mechanical)	75	75	225	0.219
Laser (Electrical)	2600	1300	455	0.250
Gas Supply			30	0.079
Thermal Management	315	315	68	0.140
Control, Command, Commn.	100	100	15	0.012
Optical/Structural	250	250	580	0.540
TOTALS	3490	2190	1388	1.161

For the near-term, we strongly recommend that NASA undertake conceptual design of the transmitter, at a relatively low level. We further suggest that consideration be given to acceleration of the needed technology verification tests into the FY86 time frame. These actions will result in considerably enhanced confidence in SCALE's success at a relatively modest cost.